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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/080,156	02/19/2002	Olaf Jose F. Hirsch	US 028003	9302

7590 03/03/2006

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EXAMINER	
ELALLAM, AHMED	

ART UNIT	PAPER NUMBER
2668	

DATE MAILED: 03/03/2006

Please find below and/or attached an Office communication concerning this application or proceeding.

Office Action Summary	Application No. 10/080,156	Applicant(s) HIRSCH ET AL.	
	Examiner AHMED ELALLAM	Art Unit 2662	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *19 February 2002*.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-20* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-20* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☒ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on *19 February 2002* is/are: a)☐ accepted or b)☒ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☐ Information Disclosure Statement(s) (PTO-1449 or PTO/SB/08) Paper No(s)/Mail Date _____.
4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other: _____.

DETAILED ACTION

Drawings

1. The drawings are objected to as failing to comply with 37 CFR 1.84(p)(5) because they do not include the following reference sign(s) mentioned in the description: the numeral character "330" is not shown in figure 3, as indicated in the specification on page 8, paragraph [028]. Corrected drawing sheets in compliance with 37 CFR 1.121(d) are required in reply to the Office action to avoid abandonment of the application. Any amended replacement drawing sheet should include all of the figures appearing on the immediate prior version of the sheet, even if only one figure is being amended. Each drawing sheet submitted after the filing date of an application must be labeled in the top margin as either "Replacement Sheet" or "New Sheet" pursuant to 37 CFR 1.121(d). If the changes are not accepted by the examiner, the applicant will be notified and informed of any required corrective action in the next Office action. The objection to the drawings will not be held in abeyance.

Specification

2. The disclosure is objected to because of the following informalities:

On page 2, paragraph [009], line 2, the term "second" is missing after "first and".

On page 5, paragraph [018], line 3, the phrase "content-free" should be changed to "contention-free" as indicated on line 9.

Appropriate correction is required.

Claim Objections

3. Claim 20 is objected to because of the following informalities:

In claim 20, line 4 reference is made to the "station" in singular form, whereas a first and second stations were previously indicated. It is not clear to which station "the station" refers. Appropriate correction is required.

Claim Rejections - 35 USC § 112

The following is a quotation of the second paragraph of 35 U.S.C. 112:

> The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

4. Claims 1-20 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

In claims 1, 12 and 20, the meaning of phrase "the contention-free period comprises a sub-contention period" is confusing because the common definition of contention-free period is understood to have no contention between stations as defined in the WLAN standards (802.11), the meaning of sub-contention period being part of the contention-free period is indefinite.

Note: the claimed " contention-free period followed by a contention period, and, the contention-free period comprises a sub-contention period" is interpreted hereinafter to be the same as *"**contention-free period followed by a contention period, and, the contention period comprises a sub-contention period**"*. Examiner believes it is more

appropriate to interpret the claimed limitation as such, because the sub-contention period would commonly belong to a contention period. In addition, the specification discloses that the stations 1-3 (DSSS/CCK stations) do not send data during the sub-contention period that is the sub-contention period doesn't belong to a free contention period.

Claims 2-11, and 13-19 depend from rejected respective claims 1 and 12, thus they are subject to the same rejections.

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

5. Claims 1-7, 11-15, and 20 are rejected under 35 U.S.C. 103(a) as being unpatentable over Young et al, US (6,990,116) in view of Admitted Prior Art, specification paragraphs [002-[003]. Hereinafter, referred to as Young and APA respectively.

Regarding claims 1, 12 and 20, with reference to figure1 and 5, Young discloses an access point AP-A 112 and a plurality of end stations A-1-A-n that are connected through a wireless connection, see column 4, lines 16-26; Young also discloses a contention free period 520 followed by a contention period 530, wherein a point coordinator at the access point sends a beacon frame 525 to all the stations in its

BSS (Base Station Subsystem), the beacon frame communicates to the stations the length of the contention-free period, where the point coordinator controls the medium during the PCF access period 527, which is followed by contention period the contention period in accordance with DCF access (Distributed Coordination Function), see column 8, lines 20-31. (Examiner interpreted the communication of the length of the contention-free period to all the stations as being the claimed *beacon frame indicating contention-free period followed by a contention period, and, the contention period comprises a sub-contention period,* because of the periodical repetition of the beacon frame, the contention period is implicitly indicated as part of the contention free period indication*).*

Young doesn't specify a first station using a first modulation scheme and a second station using a second modulation scheme, the second station using the second modulation scheme during the sub-contention period (claims 1, 12, and 20 do not specify the first modulation scheme and second modulation scheme are different, thus the first and second modulation schemes are interpreted as being the same).

However, APA specifies modulation schemes such as DSSS/CKK supported by IEEEE 802.11 standard or OFDM modulation scheme as specified by IEEE 802.11a standard. It would have been obvious to a person of ordinary skill in the art, at the time the invention was made to have the mobile stations of Young use specific modulation scheme during the contention period as specified by APA so that the WLAN of Young can utilize the standard Wireless LAN protocols. The advantage would be the implementation of the well-established WLAN protocols in Young's WLAN.

Regarding claims 2 and 13, APA discloses DSSS/CKK modulation being established as part of IEEE 802.11 standard. See [002].

Regarding claims 3 and 14, APA discloses IEEE 802.11a standard defines a physical layer based on the orthogonal frequency division multiplexing (OFDM).

Regarding claim 4, with reference to figure 5, Young shows that the contention period 530 occurs at the end of the contention free period 527.

Regarding claims 5-7 and 15, Young discloses having the access point dynamically adjust the appropriate access mechanism (DCF or PCF) (point coordination function or Distributed coordination function) based on load conditions, including the number of stations, see column 8, lines 47-67 and column 9, lines 1-10, see also figure 6.

Regarding claim 11, Young discloses the WLAN operating under IEEE 802.11 specification. (See column 2, lines 36-40).

6. Claims 8, 9, 10,16, 17, 18 and 19 are rejected under 35 U.S.C. 103(a) as being unpatentable over Young in view of APA as applied to respective claims 1 and 12 above, and further in view of Cimini, JR. et al, US 2003/0152058. Hereinafter referred to as Cimini.

Regarding claims 8, 16 and 18, as discussed above, Young in view of APA discloses substantially all the limitation of claims 8, 16 and 18 except that they do not disclose that during the contention period, the access point sends a request-to-send frame comprising information representative of second modulation scheme (as in

claims 8 and 16) and the access point receives a request-to-send frame from the second station comprising information representative of second modulation scheme (as in claim 18).

Regarding claims 9 and 17, as discussed above, Young in view of APA discloses substantially all the limitation of claims 9 and 17 except that they do not disclose that during contention period, the second station transmits request-to-send and clear-to-send frames modulated according to the second modulation scheme.

As to claims 8, 9, 16 and 17:

Cimini discloses that the DCF (Distributed coordination function) with Request to Send (RTS)/Clear to Send (CTS) has been standardized, and that

The RTS/CTS is a natural choice for adaptive coding/modulation. See paragraph [0031]. (The DCF access is implemented during the contention period as part of IEEE 802.11 standard). (Claimed the access point sends a request-to-send frame comprising information representative of second modulation scheme, during the contention period, as in claims 8 and 16, and the second station transmits request-to-send and clear-to-send frames modulated according to the second modulation scheme, during the contention period as in claim 17 (A modulation is necessary for exchanging the RTS/CTS by the wireless unit during the contention period) and the claimed access point receives a request-to-send frame from the second station comprising information representative of second modulation scheme as in claim 18) . It would have been obvious to a person of ordinary skill in the art, at the time the invention was made to have the stations of Young implement the standardized

RTS/CTS during the DCF (claimed contention period) so that the exchange of channel information (coding/modulation) would take effect prior to the data transmission begins. The advantage would be the provisioning of accurate rate adaptation and coding I the system of Young in view of APA. (See Cimini [0031].

Regarding claims 10 and 19, Cimini discloses that RTS/CTS is a natural choice for adaptive coding/modulation because the RTS/CTS pair (access point, wireless station) can exchange channel information before the data packet transmission begins so that accurate rate adaptation can occur. (Claimed the access point received from the second station an information field representative of the second modulation capability when the second station joins the local area network).

Conclusion

7. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure: See reference cited in attached form PTO-892.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to AHMED ELALLAM whose telephone number is (571) 272-3097. The examiner can normally be reached on 9-5:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Kizou Hassan can be reached on (571) 272-3088. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).

AE
Examiner
Art Unit 2662
2/24/06

JOHN PEZZLO
PRIMARY EXAMINER

Notice of References Cited	Application/Control No. 10/080,156	Applicant(s)/Patent Under Reexamination HIRSCH ET AL.	
	Examiner AHMED ELALLAM	Art Unit 2662	Page 1 of 2

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2002/0071449 A1	06-2002	Ho et al.	370/447
*	B	US-2002/0163933 A1	11-2002	Benveniste, Mathilde	370/465
*	C	US-2003/0086437 A1	05-2003	Benveniste, Mathilde	370/461
*	D	US-2003/0117984 A1	06-2003	Gavette, Sherman Leon	370/338
*	E	US-2003/0128659 A1	07-2003	Hirsch et al.	370/208
*	F	US-2003/0161340 A1	08-2003	Sherman, Matthew J.	370/445
*	G	US-2003/0161279 A1	08-2003	Sherman, Matthew J.	370/328
*	H	US-2003/0169763 A1	09-2003	Choi et al.	370/462
*	I	US-2004/0095911 A1	05-2004	Benveniste et al.	370/338
*	J	US-2004/0141522 A1	07-2004	Texerman et al.	370/466
*	K	US-2004/0196822 A1	10-2004	Proctor, James A. JR.	370/349
*	L	US-6,842,605 B1	01-2005	Lappetelainen et al.	455/13.4
*	M	US-6,990,116 B1	01-2006	Young et al.	370/445

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N	WO 01/95579 A2	12-2001	WO	Webster et al	
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Ranasinghe et al, Distributed contention-free traffic scheduling in IEEE 802.11 multimedia networks, 2001 IEEE, pages 18-28.
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Notice of References Cited	Application/Control No. 10/080,156	Applicant(s)/Patent Under Reexamination HIRSCH ET AL.	
	Examiner AHMED ELALLAM	Art Unit 2662	Page 2 of 2

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2002/0163928 A1	11-2002	Rudnick et al.	370/444
*	B	US-6,717,926 B1	04-2004	Deboille et al.	370/330
*	C	US-6,747,968 B1	06-2004	Seppala et al.	370/338
*	D	US-6,873,611 B2	03-2005	Rios, Carlos A	370/338
*	E	US-2003/0152058 A1	08-2003	Cimini et al.	370/338
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

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	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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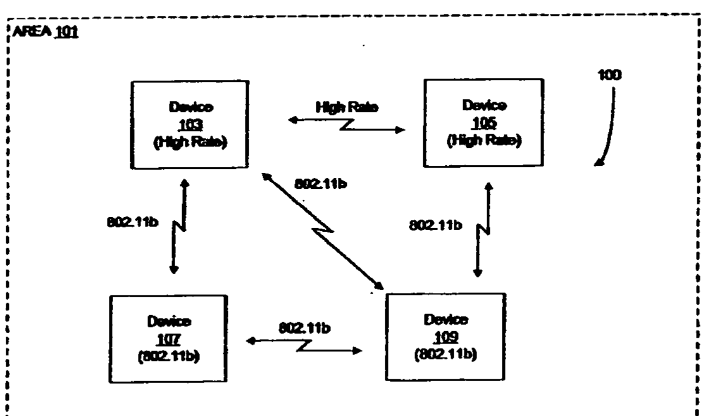
Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DUAL PACKET CONFIGURATION FOR WIRELESS COMMUNICATIONS



(57) Abstract: A dual packet configuration for wireless communications including a first portion that is modulated according to a serial modulation and second portion that is modulated according to a parallel modulation. The serial modulation may be DSSS whereas the parallel modulation may be OFDM. The first portion may include a header, which may further include an OFDM mode bit and a length field indicating the duration the second portion. The first portion may be in accordance with 802.11b to enable dual mode devices to coexist and communicate in the same area as standard 802.11b devices. The dual mode devices can communicate at different or higher rates without interruption from the 802.11b devices. The packet configuration may include an OFDM signal symbol which further includes a data rate section and a data count section. In this manner, data rates the same as or similar to the 802.11a data rates may be specified between dual mode devices. The first and second portions may be based on the same or different clock fundamentals. For OFDM, the number of subcarriers, pilot tones and guard interval samples may be modified independently or in combination to achieve various embodiments.

WO 01/95579 A2

Dual Packet Configuration for Wireless Communications

The present invention relates to wireless communications, and is particular to a dual packet configuration for use in wireless local area networks.

The U.S. Institute of Electrical and Electronics Engineers, Inc. (IEEE) 802.11 standard is a family of standards for wireless local area networks (WLAN) in the unlicensed 2.4 and 5 Gigahertz (GHz) bands. The current 802.11b standard defines various data rates in the 2.4 GHz band, including data rates of 1, 2, 5.5 and 11 Megabits per second (Mbps). The 802.11b standard uses direct sequence spread spectrum (DSSS) with a chip rate of 11 Megahertz (MHz), which is a serial modulation technique. The 802.11a standard defines different and higher data rates of 6, 12, 18, 24, 36 and 54 Mbps in the 5 GHz band. It is noted that systems implemented according to the 802.11a and 802.11b standards are incompatible and will not work together.

A new standard in the U. S. A. is being proposed, referred to as 802.11 HRb (the "HRb proposal"), which is a high data rate extension of the 802.11b standard at 2.4 GHz. The present time, the HRb proposal is only a proposal and is not yet a completely defined standard. Several significant technical challenges are presented for the new HRb proposal. It is desired that the HRb devices be able to communicate at data rates higher than the standard 802.11b rates in the 2.4 GHz band. In some configurations, it is desired that the 802.11b and HRb devices be able to coexist in the same WLAN environment or area without significant interference or interruption from each other, regardless of whether the 802.11b and HRb devices are able to communicate with each other. It may further be desired that the HRb and 802.11b devices be able to communicate with each other, such as at any of the standard 802.11b rates.

The present invention includes a dual packet configuration for wireless communication, comprising a first portion that is modulated according to a serial modulation, and a second portion that is modulated according to a parallel modulation, and preferably the serial modulation comprising direct sequence spread spectrum (DSSS); and the parallel modulation comprising orthogonal frequency division multiplexing (OFDM).

The invention also includes a wireless communication device that is configured to communicate using a dual packet configuration, comprising a transmitter configured to transmit packets with a dual configuration, a receiver configured to receive packets with a dual configuration, and the dual packet configuration including first and second portions, the first portion modulated according to a serial modulation method and the second portion modulated according to a parallel modulation method, and in which the serial modulation is direct sequence spread spectrum (DSSS) and the parallel modulation method is orthogonal frequency

division multiplexing (OFDM).

The invention furthermore includes a method of wireless communication using a dual packet configuration, comprising modulating a first portion of each packet according to a serial modulation, and modulating a second portion of each packet according to a parallel modulation, the modulating a first portion of each packet comprising modulating according to direct sequence spread spectrum (DSSS), and the modulating a second portion of each packet comprising modulating according to orthogonal frequency division multiplexing (OFDM).

Conveniently, a dual packet configuration for wireless communications according to at least one embodiment of the present invention includes a first portion that is modulated according to a serial modulation and a second portion that is modulated according to a parallel modulation. In one embodiment, the serial modulation is direct sequence spread spectrum (DSSS), and the parallel modulation is orthogonal frequency division multiplexing (OFDM). In further embodiments, the first portion may include a preamble and a header, where the preamble may be short or long. The header may further include an OFDM mode bit indicating OFDM mode, and a length field indicating the duration the second portion.

Advantageously, the first portion may be modulated in accordance with the 802.11b standard and readily received and understood by 802.11b compatible devices operating in the 2.4 GHz frequency band. Each 802.11b device receives the preamble and header and determines the duration of the dual packet from the length field, so that the 802.11b devices know how long to back off during transmission of a dual mode packet. In this manner, devices communicating with the dual mode packet configuration will not be disrupted by the 802.11b devices, and may thus coexist within the same communication area as the standard 802.11b devices.

Furthermore, devices utilizing a dual mode packet configuration according to certain embodiments may coexist with 802.11b devices in the 2.4 GHz frequency band while communicating at different or even greater data rates afforded by OFDM, such as data rates similar to the 802.11a standard. Whereas the 802.11b devices are currently limited to 11 Mbps, the dual mode devices may operate at 54 Mbps or higher depending upon the particular configuration. The OFDM mode bit indicates OFDM mode to another target OFDM device. For such OFDM embodiments, the packet configuration may include an OFDM synchronization pattern, an OFDM signal symbol and an OFDM payload. The OFDM signal symbol may further include a data rate section and a data count section for specifying the data rate the number of data bytes in the payload. In this manner, data rates the same as or similar to the 802.11a data rates may be specified between dual mode devices, such as 6, 12, 24, 36 or 54 Mbps.

In at least one embodiment, the first portion of the dual packet configuration may be

based on a first clock fundamental whereas the second portion is based on a second clock fundamental. In one embodiment, for example, the first clock fundamental is approximately 22 MHz, whereas the second clock fundamental is approximately 20 MHz. The 22 MHz clock signal is the clock fundamental for the 802.11b standard to enable compatibility with 802.11b devices when operating in the 2.4 GHz band. The 20 MHz clock fundamental is typical for the OFDM modulation technique, so that an increased data rate is achieved within the 2.4 GHz band.

In alternative embodiments, the first and second portions of the dual packet configuration are both based on a single clock fundamental, such as 22 MHz. Various embodiments are contemplated for the single clock fundamental. In one embodiment, each OFDM symbol includes a guard interval with a standard number of samples for OFDM, such as 16 samples according to 802.11a. Alternatively, the guard interval includes an increased number of samples, such as 24 samples.

In yet further embodiments, each OFDM symbol in the packet configuration may include a standard number of frequency subcarriers, such as 52 frequency subcarriers according to 802.11a. Alternatively, a reduced number of frequency subcarriers may be utilized, such as 48 subcarriers. In one embodiment, each frequency subcarrier is a data subcarrier whereas in another embodiment, pilot tones are included. In yet another embodiment, each of the frequency subcarriers are initially data subcarriers and a subset of the data subcarriers is discarded and replaced with a corresponding number of pilot tones for transmission. Upon reception of the packet, the discarded data subcarriers are recreated using received data, such as, for example, application of error correction code (ECC) techniques.

A wireless communication device according to the present invention includes a transmitter and a receiver where each are configured to communicate with a dual packet configuration. The dual packet configuration includes first and second portions, where the first portion is configured according to a serial modulation technique and where the second portion is configured according to a parallel modulation technique. As described previously, the dual packet configuration may utilize DSSS modulation as the serial modulation technique and OFDM as the parallel modulation technique. The wireless communication device may include two separate clock sources if utilizing a dual packet configuration based on first and second clock fundamentals. Alternatively, a single clock source may be utilized if the first and second portions are based on the same clock fundamental. The dual packet configuration utilized by the wireless communication device is according to any of the various embodiments described previously.

In further embodiments, the transmitter and receiver may each be capable of communicating in a super short mode in which only the second portion is utilized. The first, serial portion is not used, so that overall data throughput may be increased. The super short mode is used only for dual mode devices and is generally not compatible with single mode devices. For example, the parallel modulation mode is not compatible with the serial modulation techniques utilized by the 802.11b devices, so that a dual mode device may not coexist or communicate in the same area as active 802.11b devices. For embodiments in which the serial modulation for the first packet portions are 802.11b compatible, the super short mode is advantageous when 802.11b devices are shut off or otherwise not active in the same area, so that the dual packet mode devices may be operated with enhanced data throughputs.

In yet a further embodiment, the transmitter and receiver may each be capable of communicating in a standard mode in which the second portion is modulated according to the serial modulation. For example, this mode may be advantageous when the serial modulation is compatible with other devices, such as 802.11b devices. Thus, the dual mode devices may include the capability to communicate with the 802.11b devices in standard mode at the standard 802.11b rates, while also able to communicate with other dual mode devices at different or higher data rates.

A method of wireless communication using a dual packet configuration according to embodiments of the present invention includes modulating a first portion of each packet according to a serial modulation and modulating a second portion of each packet according to a parallel modulation. The serial modulation may be DSSS and the parallel modulation may be OFDM. The method may further include the various dual packet embodiments described previously. The method may further comprise switching to a super short mode of operation in which only the second portion modulated according to the parallel modulation is utilized for communications. The super short mode enables enhanced communications with other dual mode devices. The method may further include switching to a standard mode of operation in which the second portion is modulated according to the serial modulation of the first portion. For 802.11b compatible embodiments, the standard mode enables direct communication with 802.11b devices and enhanced communication with other dual mode devices.

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a block diagram of a WLAN system including four devices operating within the same room or area, where two of the devices are implemented according to the 802.11b standard and the other two are implemented according to the HRb proposal.

FIG. 2 is a simplified block diagram of an exemplary transceiver according to one embodiment of the present invention that may be utilized in either or both of the HRb devices of FIG. 1.

FIG. 3A is a graph diagram of a packet configuration utilizing a long preamble.

FIG. 3B is a graph diagram of an alternative packet configuration utilizing a short preamble.

FIG. 4 is a graph diagram of an exemplary header, which may be used as the header for the packet configurations of FIGs 3A or 3B.

FIG. 5 is a graph diagram of a packet configuration implemented according to a dual clock fundamental embodiment of the present invention.

FIG. 6A is a simplified block diagram of a transceiver configured to utilize the packet configuration of FIG. 5.

FIG. 6B is a simplified block diagram of an alternative transceiver configured to utilize the packet configuration of FIG. 5.

FIGs. 7A-7C are graph diagrams illustrating a packet configuration utilizing a single clock fundamental.

FIGS. 8A-8C are graph diagrams illustrating another exemplary packet configuration utilizing a single clock fundamental and a standard number of samples in the guard interval.

FIG. 9A is a graph diagram of packet configuration utilizing 48 subcarriers.

FIG. 9B is a graph diagram illustrating the subcarriers of FIG. 9A including 44 data subcarriers and four pilot tones.

FIG. 9C is a graph diagram of an alternative subcarrier configuration for the packet configuration of FIG. 9 including 48 data subcarriers.

FIGS. 10A and 10B illustrate the packet configuration of FIG. 9 in which four of the 48 data subcarriers are replaced with pilot tones.

FIG. 11 is a table diagram illustrating comparisons of the various OFDM embodiments illustrating variations in data rates, OFDM symbol duration, spectral width, thermal noise and delay spread spectrum as a result of variations in the clock rates, number of subcarriers, number of pilot tones, and the number of samples in the guard interval.

FIG. 12 is a graph diagram of an exemplary packet configuration according a super short OFDM preamble embodiment.

Figure 1 is a block diagram of a wireless local area network (WLAN) system 100 operating within a particular room or area 101, including four WLAN devices 103, 105, 107 and 109 (103-109) are located within the area 101. The devices 103 and 105 are implemented according to at least one of several embodiments of the present invention with the HRb proposal in mind, whereas the devices 107 and 109 are implemented according to the 802.11b

standard. All of the devices 103-109 operate in the 2.4 GHz band. The devices 103-109 may be any type of wireless communication device, such as any type of computer (desktop, portable, laptop, etc.), any type of compatible telecommunication device, any type of personal digital assistant (PDA), or any other type of network device, such as printers, fax machines, scanners, hubs, switches, routers, etc. It is noted that the present invention is not limited to the HRb proposal, the 802.11b standard, the 802.11a standard or the 2.4 GHz frequency band, although these standards and frequencies may be utilized in certain embodiments.

The devices 107 and 109 communicate with each other at any of the standard 802.11b rates, including 1, 2, 5.5 and 11 Mbps. The devices 103 and 105 are dual mode devices that communicate with each other at different or higher data rates using a dual packet configuration according to any one of several embodiments described below, such as the standard 802.11a data rates of 6, 9, 12, 18, 24, 36, 48 or 54 Mbps. Alternative data rate groups are considered herein, such as a first group of 6.6, 9.9, 13.2, 19.8, 26.4, 39.6, 52.8 or 59.4 Mbps, or a second group of 5.5, 8.25, 11, 16.5, 22, 33, 44 or 49.5 Mbps, or a third group of 6.05, 9.075, 12.1, 18.15, 24.2, 36.3, 48.4 or 54.45 Mbps. The second group is advantageous as including two of the 802.11b standard data rates, namely 5.5 and 11 Mbps.

In one or more first embodiments, the dual mode devices 103-109 may operate or coexist in the same area 101 without significant interference from each other, where the devices 103, 105 communicate with each other at different or higher data rates than the 802.11b devices 107, 109. In the first embodiments, the devices 103, 105 may communicate with each other while the devices 107, 109 may communicate with each other, but the devices 103, 105 do not communicate with the devices 107, 109. In one or more second embodiments, at least one of the dual mode devices 103, 105 is configured with a standard mode to be able to communicate with either of the devices 107, 109 at any one or more of the standard 802.11b data rates. In at least one third embodiment, the dual mode devices 103, 105 are configured with a super short mode and communicate at different or higher data rates and are incompatible with the devices 107 and 109, so that the devices 103-109 are not able to coexist within the same area 101. The dual mode devices 103, 105 may be implemented to operate in the 2.4 GHz band, although other frequency bands are contemplated.

In the first or second embodiments, it is desired that the devices 103 and 105 be able to communicate with each other without interruption or interference from either of the devices 107 and 109. This presents a significant technical challenge since the devices 103, 105 operate at different data rates when communicating with each other. The present invention solves this problem by enabling the devices 103 and 105 to be implemented to be able to communicate with

each other at different or at higher data rates while residing in a same area 101 as the 802.11b devices 107, 109. Further, in the second embodiments the devices 103, 105 may also communicate with either of the devices 107, 109 at the 802.11b data rates

FIG. 2 is a simplified block diagram of an exemplary dual mode transceiver 200 according to one embodiment of the present invention that may be utilized in either or both of the devices 103, 105. The transceiver 200 includes an exemplary dual mode transmitter 201 and exemplary dual mode receiver 203. Within the transmitter 201, input data is provided to an encoder 211 at a particular rate of transmission. The data from the encoder 211 is provided to a modulator and filter 213, which modulates the encoded data onto a transmission signal asserted via a corresponding antennae 215. The transmitted signal is received by an antennae 221 of the receiver 203, which provides the received signal to an equalizer and retrain system 223. The equalizer/retrain system 223 demodulates the received signal and provides a demodulated signal to a decoder 225, which provides the output data. Within the decoder 225, a soft decision block 227 provides soft decision signals to a hard decision block 229, which formulates the final output data.

FIG. 3A is a graph diagram of a dual packet configuration 300 according one embodiment of the present invention utilizing a long preamble. The packet configuration 300 includes a long preamble 301, which may be implemented according to the 802.11b standard having 144 bits. Also according to the 802.11b standard, the long preamble is transmitted at a data rate of 1 Mbps. The long preamble 301 is followed by a header 303, which again may be implemented according to the 802.11b standard having 48 bits transmitted at a data rate of 1 Mbps. In accordance with the 802.11b standard, the preamble 301 and header 303 are transmitted in approximately 192 microseconds (μsecs). Instead of a normal 802.11b packet however, the packet configuration 300 includes an orthogonal frequency division multiplexing (OFDM) synchronization (sync) pattern 305, followed by an OFDM signal symbol 306, followed by an OFDM payload 307. OFDM is a parallel modulation technique utilizing a plurality of subcarrier frequencies transmitted in parallel for each of a plurality of OFDM symbols, as further described below.

The OFDM sync pattern 305 may be implemented according to the 802.11a standard and is transmitted in approximately 16 μsecs. For example, the OFDM sync pattern 305 may be implemented according to the OFDM sync pattern specified in the 802.11a standard, which is a special pattern that enables a receiver circuit to determine precisely when the first data bit of the payload will arrive. The OFDM signal symbol 306 may also be implemented according to the 802.11a standard and is transmitted in approximately 4 μsecs. As shown, the OFDM signal

symbol 306 includes a data rate section 308 and a data count section 309. The data rate section 308 is a bit field specifying the data rate, such as the standard 802.11a rates, and the data count section 309 is a bit field indicative of the number of data bytes in the payload 307. In one embodiment, the OFDM payload 307 is comprised of OFDM symbols at any one of the 802.11a standard data rates of 6, 9, 12, 18, 24, 36, 48, or 54 Mbps, which are PHY sublayer Service Data Units (PSDU) selectable. The OFDM payload 307 is transmitted in "K" μsecs, where K is not necessarily directly related to the number of OFDM symbols in the payload portion.

FIG. 3B is a graph diagram of an alternative packet configuration 310 incorporating a short preamble 311. In an embodiment in accordance with 802.11b, the packet configuration 310 includes a 72-bit preamble 311 transmitted at 1 Mbps, followed by a header 313 transmitted at 2 Mbps, followed by an OFDM sync pattern 315 similar to the OFDM sync pattern 305, followed by an OFDM signal symbol 316 similar to the OFDM signal symbol 306, which is followed by an OFDM payload 317 comprising OFDM symbols at any of the standard 802.11a data rates. The data rates are PSDU selectable in a similar manner as the OFDM payload 307. According to 802.11b, the short preamble 311 and the header 313 are transmitted in approximately 96 μsecs. Again according to 802.11a, the OFDM sync pattern 315 is transmitted in 16 μsecs, the OFDM signal symbol 316 is transmitted in 4 μsecs and the OFDM payload 317 is transmitted in K μsecs.

The short preamble 311 is utilized to reduce overhead and allow more data to be transmitted in the same amount of time as compared to the long preamble 301. A system utilizing the short preamble, however, may need a higher signal to noise (SNR) ratio to achieve accurate reception of data. The OFDM signal symbol 316 may also include a data count and data rate similar to the OFDM signal symbol 306 to specify the number of information bytes and OFDM data rate of the payload portion.

FIG. 4 is a graph diagram of an exemplary header 400, which may be used as the header 303 for the packet configuration 300 or the header 313 for the packet configuration 310. The header 400 may be implemented in a similar manner as the 802.11b standard header including an 8-bit signal field 401, an 8-bit service field 403, a 16-bit length field 405, and a 16-bit cyclical redundancy check (CRC) field 407. The header 400 is modified, however, to include OFDM mode bit 404 within the service field 403 to denote the OFDM mode of operation. The signal field 401 is normally used to accommodate rates of up to 25.5 Mbps according to 802.11b. However, if the OFDM mode is indicated by the OFDM mode bit 404, then the signal field 401 is interpreted differently as any data rate supported by the transmitting device, such as either of the devices 103, 105. In some embodiments, the 802.11a standard data rates are used,

including 6, 9, 12, 18, 24, 36, 48, or 54 Mbps. Alternative data rates are used in alternative embodiments, as further described below. The length field 405 is utilized in a similar manner as 802.11b and indicates the duration or number of μsecs for transmission of the OFDM sync pattern, signal symbol and payload, such as either of the OFDM sync patterns 305, 315 (16 μsecs), signal symbols 306, 316 (4 μsecs) and data payloads 307, 317 (K μsecs). For example, the length field 405 includes a bit pattern representing the number K+ 20 μsecs. If actual packet length is equal to a fractional number of μsecs, then the length field 405 specifies the next highest integer. For example, an actual packet length of 237.4 μsecs would use 238 in the length field. The CRC field 407 is utilized in a similar manner as the standard header for 802.11b.

In general, the dual packet configurations 300, 310 include a first portion comprising the preamble and header and a second portion comprising the OFDM sync, signal symbol and payload. The first portion is modulated according to serial modulation, such as direct sequence spread spectrum (DSSS) according to 802.11b, and the second portion is modulated according to parallel modulation, such as OFDM. It is appreciated that either dual packet configuration 300 or 310 utilized by either of the devices 103, 105, when configured according to the serial modulation of 802.11b, are readily received and understood by either of the devices 107, 109. In particular, the long preamble 301 and header 303 of the packet configuration 300 or the short preamble 311 and the header 313 of the packet configuration 310, are implemented in a similar manner and transmitted at the same data rates as those of standard 802.11b devices. Regardless of whether the 802.11b devices 107, 109 are able to detect or otherwise interpret the OFDM mode bit 404 indicating OFDM mode, the length field 405 is interpreted in the same manner as a duration of the second portion of the packet, so that both of the devices 107, 109 are informed of the length of the OFDM sync, signal symbol and payload of a packet transmitted by either of the devices 103, 105. In this manner, any 802.11b device in the same area, such as the area 101, as a dual mode device utilizing the dual packet configurations 300 or 310 is sufficiently informed of the amount of time to back off during transmission of a dual mode packet regardless of its data rate.

The devices 103, 105 are configured to detect the OFDM mode bit 404 in the service field 403 and to correspondingly interpret the signal field 401 to therefore identify the modulation technique and the data rate of transmission to enable communications between the devices 103, 105. When the OFDM mode is indicated, the devices 103, 105 are further configured to detect the OFDM sync pattern, read the OFDM signal symbol, and retrieve the data in the OFDM payload. In this manner, when the devices 103, 105 are utilizing the dual packet configurations 300 or 310, they may communicate at different or higher data rates while coexisting within the

same area 101 as any 802.11b device, such as the devices 107, 109. The devices 103, 105 may further be configured with a standard mode to communicate with the devices 107, 109 at the standard 802.11b data rates if desired. For example, the devices 103, 105 may include the necessary 802.11b communication circuitry. It is noted that the devices 107, 109 are unable to understand or receive and demodulate the OFDM sync, signal symbol and payload portions of the packet configurations 300 or 310 in OFDM mode. The devices 103, 105 may further be configured to switch to a super short mode, described further below, in which only the second, parallel modulation portion of the packet configurations are utilized. In the super short mode, the devices 103, 105 may not coexist with active devices 107, 109, and thus may be used when the devices 107, 109 are switched off or otherwise removed from the area 101.

FIG. 5 is a graph diagram of a dual packet configuration 500 implemented according to a dual clock fundamental embodiment of the present invention. The packet configuration 500 is shown corresponding to either of the packet configurations 300 or 310, including a preamble 501, followed by a header 503, followed by an OFDM sync pattern 505, followed by an OFDM signal symbol 506, followed by an OFDM payload 507. The preamble 501 is according to either of the long or short preambles 301, 311. The header 503 is implemented according to either the headers 303 or 313 depending upon the rate of transmission (1 or 2 Mbps). The OFDM sync pattern 505 is implemented according to either of the OFDM sync patterns 305 or 315. The OFDM signal symbol 506 is implemented according to either of the OFDM signal symbols 306 or 316, and may include data rate and data count fields in a similar manner as described for the packet configuration 300. The OFDM payload 507 is implemented according to either of the OFDM payloads 307, 317.

For the packet configuration 500, the preamble 501 and the header 503 comprise a first portion that is transmitted utilizing a first clock fundamental with serial modulation, whereas the OFDM sync pattern 505, the OFDM signal symbol 506 and the OFDM payload 507 comprise a second portion that is transmitted utilizing a second clock fundamental with parallel modulation. For 802.11b, the first clock fundamental for the preamble 501 and the header 503 is 22 Megahertz (MHz). The second clock fundamental for the OFDM sync pattern 505 and the payload 507 may be according to 802.11a, such as 20 MHz. In this manner, the packet configuration 500 is transmitted using two separate clock fundamentals requiring a switch in sampling rate between the header 503 and the OFDM sync pattern 505. Several embodiments are considered for providing a rate change solution between the 22 and 20 MHz clock fundamentals.

FIG. 6A is a simplified block diagram of a dual mode transceiver 600 configured to

utilize the dual packet configuration 500. The transceiver 600 includes a dual mode transmitter 601 and a dual mode receiver 603. Within the transmitter 601, the transmit signal is divided into first and second quadrature portions which are provided to an I channel digital-to-analog converter (DAC) 605 and to a Q channel DAC 607. The I and Q channel DACs605, 607 receive a clock signal from a switch 609, which receives and switched between a 40 MHz clock signal from a clock source 613 and a 44 MHz clock signal from a clock source 611. The 40 MHz clock signal is based on the 20 MHz clock fundamental whereas the 44 MHz clock signal is based on the 22 MHz clock fundamental. The 22 MHz receive clock and the 44 MHz transmit clock are harmonically related to the 11 MHz 802.11b DSSS chip rate. The switch 609 is controlled by a clock mode signal to select either the 44 MHz clock signal or the 40 MHz clock signal. In this manner, the preamble 501 and the header 503 are transmitted while the clock mode signal selects the 44 MHz clock 611 whereas the OFDM sync pattern 505, signal symbol 506 and payload 507 are transmitted utilizing the 40 MHz clock signal.

For the receiver 603, an I channel analog-to-digital (ADC) 615 and a Q channel ADC 617 receive the respective quadrature portions of the received signal. A switch 619 receives the clock mode signal and controls or otherwise provides either a 22 MHz clock signal from a clock source 621 or a 20 MHz clock signal from a clock source 623. The receiver 603 is configured to receive the preamble 501 and header 503 with the 22 MHz clock signal selected, and then to receive the OFDM sync pattern 505, signal symbol 506 and payload with the 20 MHz clock signal selected. The conversion between the two clock signals may be handled in various ways by the base band processor (BBP), such as an on-chip phase lock loop (PLL) or two external clock inputs to the BBP. The transmitter 601 and the receiver 603 must each include two separate clock sources for switching between the different clock fundamental signals. Further, the DACs 605, 607 and the ADCs 615, 617 must be configured to operate at either clock fundamental. In this manner, the transceiver 600 is a somewhat complicated solution requiring additional circuitry.

FIG. 6B is a simplified block diagram of an alternative transceiver 630. The transceiver 630 includes a transmitter 631 and a corresponding receiver 633. Here a polyphase filter is used to provide the clock change during the OFDM portion of the signal. During the 802.11b portion of the signal, the polyphase filter is not needed, since a clock of 22 or 44 MHz is already provided. During the OFDM portion of the signal, the polyphase filter is activated to rate shift the signal samples between the two clock domains. The transmitter 631 operates based on a 40 MHz input signal, utilizing a 40 MHz clock source 634, provided to a polyphase filter 635. The outputs of the polyphase filter 635 are provided to an I channel DAC 637 and a Q channel DAC

639, which are operated at a 44 MHz clock signal provided from a clock source 641. For the receiver 633, the receive signals are provided to an I channel ADC 643 and a Q channel ADC 645. The outputs of the ADC 643, 645 are provided to a polyphase filter 647, which asserts a 20 MHz output signal utilizing a 20 MHz clock source 651. A 22 MHz clock signal from a clock source 649 provides the clocking signal for the ADC 643, 645. It is noted that the transmitter 631 and the receiver 633 both utilize two separate clock sources. In particular, the transmitter 631 requires the 40 MHz clock source 634 and the 44 MHz clock source 641, whereas the receiver 633 utilizes the 22 MHz clock source 649 and the 20 MHz clock source 651. Thus, additional clocking circuitry is needed and the polyphase filter 635, 647 are rate change filters that are relatively complicated.

FIGs. 7A-7C are graph diagrams illustrating a dual packet configuration 700 implemented according to an alternative embodiment of the present invention utilizing a single clock fundamental and with increased samples in the guard interval. As shown in FIG. 7A, the packet configuration 700 is similar to the packet configuration 500 and includes a first, serially modulated portion with a preamble 701 and a header 703, and a second parallel modulation portion including an OFDM sync pattern 705, an OFDM signal symbol 706 and a payload portion 707. The OFDM signal symbol 706 may include data rate and data count fields in a similar manner as described for the packet configuration 300. The preamble 701 is similar to the preamble 501 and may be implemented according to either of the preambles 301, 311 depending upon whether a long or short preamble is desired. Also, the header 703 is implemented according either the header 303 or 313 depending upon the rate of transmission such as either 1 or 2 Mbps. The packet configuration 700 is different, however, in that the entire packet is transmitted utilizing a single clock fundamental. In one embodiment, the clock fundamental is 22 MHz according to 802.11b. Since the OFDM sync pattern 705, signal symbol 706 and payload 707 are implemented utilizing OFDM, they are slightly modified as compared to the 802.11a standard.

FIG. 7B is a graph diagram of an exemplary OFDM symbol 710 that utilizes a 22 MHz sampling fundamental according to one embodiment of the dual packet configuration 700. The OFDM symbol 710 is similar to a standard 802.11a OFDM symbol and includes a guard interval 711 followed by an Inverse Fast Fourier Transform (IFFT) / FFT span 713. The OFDM symbol 710 deviates from the 802.11a standard in that the cyclic extension or guard interval 711 is comprised of 24 samples rather than the standard 16 samples. The IFFT/FFT span 713 includes 64 samples similar to the 802.11a standard. It is noted however that the OFDM symbol 710, while transmitted in 4 μsecs similar to the 802.11a standard, is based on a 22 MHz sampling

fundamental unlike the 802.11a standard based on 20 MHz.

FIG. 7C is a graph diagram illustrating the tone spacing of 52 subcarriers 720 of the OFDM symbol 710, each subcarrier denoted Sn, where n varies from 0 to 51. The subcarriers S0-S51 include data subcarriers and pilot tones. The frequency span 720 for each OFDM symbol 710 is approximately 17 to 18 MHz (~17.875 MHz) with a tone spacing between each of the 52 subcarriers of approximately 343 to 344 kilohertz (kHz) (343.75 kHz). The 52 subcarriers according to the 802.11a standard has a frequency span of approximately 16.25 MHz with a tone spacing of approximately 312.5 kHz, with four (4) pilot tones. The OFDM symbol 710 therefore exhibits slightly more loss as compared to a standard 802.11a symbol. A dual mode transceiver implementation configured to send and receive the packet configuration 700 utilizing the OFDM symbol 710 does not require two separate clock sources or otherwise utilize two separate clock fundamentals. Instead, only a single clock fundamental, such as 22 MHz, is necessary. However, a slight loss is experienced with an implementation for the packet configuration 700, such as approximately 0.5 dB. Furthermore, more severe filtering is required for the packet configuration 700 at the single clock fundamental as compared to a standard 802.11a configuration since the overall spectrum is approximately 10% broader. The spectral mask for the packet configuration 700 is also slightly harder to meet as compared to the standard 802.11a.

FIGS. 8A-8C are graph diagrams illustrating another exemplary dual packet configuration 800 implemented according to an alternative embodiment utilizing a single clock fundamental and a standard number of samples in the guard interval. As shown in FIG. 8A, the packet configuration 800 is similar to the packet configuration 700, including a preamble 801, a header 803, an OFDM sync pattern 805, an OFDM signal symbol 806 and a payload portion 807, and is based on a single clock fundamental, such as 22 MHz, except that the 802.11a OFDM symbol waveform is effectively unmodified. Again, the OFDM signal symbol 806 may include data rate and data count fields in a similar manner as described for the packet configuration 300. As shown in FIG. 8B, for example, the guard interval 811 utilizes the 802.11a standard 16 samples rather than the 24 samples of the guard interval 711. The OFDM symbol 810 is therefore transmitted in just over 3.5 μsecs or approximately 3.63637 μsecs rather than 4 μsecs.

The dual packet configuration 800 includes 52 subcarriers 820 for each of the OFDM symbols 810, as shown in FIG. 8C. The data rates for the packet configuration 800 is slightly modified as compared to the data rate of the packet configuration 700. In particular, the data rates for the packet configuration 800 ranges from 6.6, 9.9, 13.2, 19.8, 26.4, 39.6, 52.8, or 59.4 Mbps, which are slightly greater than the data rates for the packet configuration 700. The

spectral width for the packet configuration 800 is approximately 10% wider as compared to 802.11a. One advantage is that the packet configuration 800 is based on the same clock fundamental so there is no need for clock switching or two different clock generators or circuitry. Another advantage of the packet configuration 800 over the packet configuration 700 is that there is about the same loss as compared to 802.11a and not the greater loss of 0.5 dB as experienced for the packet configuration 700. Further, the Root Mean Square Delay Spread Performance (RMS DS) for the packet configuration 800 is approximately 10% worse as compared to 802.11a.

FIG. 9A is a graph diagram of dual packet configuration 900 similar to the dual packet configurations 700 and 800, including a first portion comprising a preamble 901and a header 903, and a second portion including an OFDM sync pattern 905, an OFDM signal symbol 906 and a payload portion 907. The dual packet configuration 900 operates with the same or a single clock fundamental, such as 22 MHz, except that the OFDM waveform is modified to include a reduced number of frequency subcarriers, such as only 48 subcarriers rather than 52 subcarriers. Again, the OFDM signal symbol 906 may include data rate and data count fields in a similar manner as described for the packet configuration 300. The 802.11a standard specifies a total number of subcarriers as 52 which includes 48 data subcarriers and 4 pilot tones. Utilizing 48 subcarriers rather than 52 generates a narrower spectrum although the spectral width is essentially the same as the 802.11a standard. The packet configuration 900, however, may be modified in several ways to generate multiple embodiments of the present invention as further described below.

FIG. 9B is a graph diagram illustrating the subcarriers 910 according to one embodiment of the dual packet configuration 900 utilizing 44 data subcarriers and four (4) pilot tones. In this configuration, there are 44 data subcarriers, denoted D0, D1, ... D43, and 4 pilot tones, denoted P0, P1, P2 and P3. As shown in FIG. 9B, the organization of the subcarriers 910 is a first data subcarrier D0, followed by a first pilot tone P0, followed by the second data subcarrier D1, which is then followed by the second pilot tone P1. Then, the data subcarriers D2 to D41 are sequentially placed in order, followed by the third pilot tone P2, the 43rd data subcarrier D42, the fourth pilot tone P3, and finally the last data subcarrier D43. The locations of the pilot tones can vary from that shown. The figure merely illustrates one possibility.

FIG. 9C is a graph diagram of an alternative subcarrier configuration 920 for the packet configuration 900 in which all 48 subcarriers are data subcarriers, denoted D0-D47. In this embodiment, there are no pilot tones, and the provided data rates are the same as that of 802.11a with 24 samples in the guard interval. However, if only 16 samples are utilized in a

similar manner as shown in FIG. 8B, then slightly different data rates are achieved at the 22 MHz clock fundamental, where each respective data rate is multiplied by approximately 1.1. FIGS. 10A and 10B illustrate yet another alternative embodiment of the subcarrier configuration for the dual packet configuration 900 in which four data subcarriers are replaced with pilot tones. As shown in FIG. 10A, the 48 subcarriers are all data subcarriers denoted D0-D47. However, as shown at 1001, the data subcarriers D1, D3, D44 and D46 are punctured and discarded. As shown in FIG. 10B at 1003, the discarded data subcarriers are replaced with four pilot tones P0, P1, P2 and P3 respectively. The pilot tones are normally used to keep the phase lock loop (PLL) circuitry healthy. It is noted, however, that the PLL may track on the data carriers instead when no pilot tones are present. The discarded data is reconstructed, recreated or otherwise regenerated by the receiver using the received data that was not discarded. The data may be reconstructed using Error Correction Code (ECC) techniques or the like, such as utilizing forward error correction (FEC) or the like. The locations of the pilot tones can vary from that shown. The figure merely illustrates one possibility

Another variation for all of the dual packet configuration 900 embodiments is to change the number of samples in the cyclic extension or guard interval between 24 and 16 samples in a similar manner as described previously for the dual packet configuration 700 and 800 as shown in FIGS. 7B and 8B. For the 48 subcarrier embodiments, changing the number of samples in the cyclic extension from 24 to 16 changes the OFDM symbol duration from 4 μsecs to 3.63637 μsecs. Furthermore, the resulting data rates may be changed from the 802.11a and 802.11b standards.

FIG. 11 is a table diagram illustrating comparisons of the various dual packet configurations described heretofore illustrating variations in data rates, OFDM symbol duration, spectral width, thermal noise performance and delay spread performance as a result of variations in the clock rates, number of subcarriers, number of pilot tones, and the number of samples in the cyclic extension or guard interval. The thermal noise performance is measured as energy per information bit (Eb) per noise density or strength (No) and is independent of bandwidth. Delay spread performance provides an indication of multipath-induced signal dispersion caused by echoes and reflections and is measured as root-mean-square delay spread (RMS DS). Each of the embodiments have an embodiment number from 1 to 9, followed by reference numbers illustrating the particular packet configuration. For example, embodiment 1 is configured according to packet configuration 500, embodiment 4 is configured according to packet configuration 900 with 48 data subcarriers of configuration 910 with 24 samples like configuration 710, and embodiment 9 is configured according to packet

configuration 900 with 44 data subcarriers and data subcarrier puncture and pilot tone replacement of configurations 1000, 1010, with 16 samples as in configuration 810. Embodiment 1 utilizes 2 clock fundamentals of 20 and 22 MHz, whereas embodiments 2-9 utilize a single clock fundamental of 22 MHz. Embodiments 1, 2 and 3 utilize 52 subcarriers, whereas embodiments 4-9 utilize 48 subcarriers. Embodiments 1-4, 6, 7 and 9 utilize four pilot tones whereas embodiments 5 and 8 utilize no pilot tones. Embodiments 1, 3, 7, 8 and 9 utilize 16 samples in the guard interval, whereas embodiments 2, 4, 5 and 6 utilize 24 samples in the guard interval.

Embodiments 3, 7, 8 and 9 result in slightly modified OFDM symbol duration of approximately 3.64 μsecs. The spectral width for embodiment 1 is the same as that as 802.11a standard. Embodiments 2 and 3 exhibit 10% wider spectral width than 802.11a whereas embodiments 4-9 exhibit 0.83% wider spectral width than 802.11a. The thermal noise performance for embodiments 1, 3, 7 and 8 are approximately the same as that of 802.11a, whereas embodiments 2, 4-6 and 9 exhibit slightly worse noise performance than 802.11a. The delay spread performance for embodiment 1 is the same as that as 802.11a. Embodiments 2, 4, 5, and 6 exhibit 50% better delay spread performance as compared to 802.11a, whereas embodiments 3, 7, 8 and 9 exhibit 10% worse delay spread performance as compared to 802.11a. FIG. 12 is a graph diagram of an exemplary packet configuration 1200 according a super short mode of operation. In general, the first, serially modulated packet portions are dropped for the super short mode. In the embodiment shown, the packet configuration 1200 includes an OFDM sync pattern 1201, followed by an OFDM signal symbol 1203, followed by an OFDM payload 1205. It is understood that other parallel modulation techniques may be utilized. A data rate section 1207 and a data count section 1209 are provided in the signal symbol 1203. The data rate section 1207 is a bit field specifying the data rate, such as the standard 802.11a rates, and the data count section 1209 is a bit field indicative of the number of data bytes in the payload 1205. The packet configuration 1200 does not include a standard 802.11b header and is therefore incompatible and not otherwise interoperable or coexistent with 802.11b devices. The entire packet configuration 1200 utilizes a single clock source, such as 20 MHz, to simplify the transceiver circuitry. The packet configuration 1200 may be utilized by either of the devices 103, 105 within the area 101 to communicate with each other. However, the standard 802.11b devices 107, 109 are not compatible and may not coexist within the same area 101 as the devices 103, 105 utilizing the super short preamble option.

A dual packet configuration for wireless communications according to at least one embodiment of the present invention enables compatibility with existing devices based on a

serial modulation while enabling communication at different or higher data rates by using parallel modulation for the payload. In particular, the dual packet configuration includes a first portion that is modulated according to a serial modulation and a second portion that is modulated according to a parallel modulation. A dual packet configuration with a first portion comprising a preamble and header modulated with DSSS serial modulation according to 802.11b in the 2.4 GHz band enables dual mode devices to coexist in the same communication area as 802.11b compatible devices. The header includes a length field that specifies the duration of the second portion of the dual packet, so that 802.11b devices know how long to back off. The second portion modulated with a parallel modulation, such as OFDM or the like, enables the dual mode devices to communicate at different or higher rates, such as up to 54 Mbps or more, without interruption from the 802.11b devices.

In some embodiments, dual mode transmitters and receivers may each be capable of communicating in a super short mode in which only the second portion is utilized. The first, serial portion is not used, so that overall data throughput may be increased. The super short mode is used only for dual mode devices and is generally not compatible with single mode devices. For example, the parallel modulation mode is not compatible with the serial modulation techniques utilized by the 802.11b devices, so that a dual mode device may not coexist or communicate in the same area as active 802.11b devices. For embodiments in which the serial modulation for the first packet portions are 802.11b compatible, the super short mode is advantageous when 802.11b devices are shut off or otherwise not active in the same area, so that the dual packet mode devices may be operated with enhanced data throughputs.

In other embodiments, the dual mode transmitters and receivers may each be capable of communicating in a standard mode in which the second portion is modulated according to the serial modulation. For example, this mode may be advantageous when the serial modulation is compatible with other devices, such as 802.11b devices. Thus, the dual mode devices may include the capability to communicate with the 802.11b devices in standard mode at the standard 802.11b rates, while also able to communicate with other dual mode devices at different or higher data rates.

A dual packet configuration for wireless communications including a first portion that is modulated according to a serial modulation and a second portion that is modulated according to a parallel modulation. The serial modulation may be DSSS whereas the parallel modulation may be OFDM. The first portion may include a header, which may further include an OFDM mode bit and a length field indicating the duration the second portion. The first portion may be in accordance with 802.11b to enable dual mode devices to coexist and

communicate in the same area as standard 802.11b devices. The dual mode devices can communicate at different or higher data rates without interruption from the 802.11b devices. The packet configuration may include an OFDM signal symbol which further includes a data rate section and a data count section. In this manner, data rates the same as or similar to the 802.11a data rates may be specified between dual mode devices. The first and second portions may be based on the same or different clock fundamentals. For OFDM, the number of subcarriers, pilot tones and guard interval samples may be modified independently or in combination to achieve various embodiments.

Claims:

1. A dual packet configuration for wireless communication, comprising a first portion that is modulated according to a serial modulation, and a second portion that is modulated according to a parallel modulation, and preferably the serial modulation comprising direct sequence spread spectrum (DSSS); and the parallel modulation comprising orthogonal frequency division multiplexing (OFDM).

2. A dual packet configuration as claimed in claim 1, wherein the first portion includes a preamble and a header, in which the preamble comprises a long preamble, or a short preamble.

3. A dual packet configuration as claimed in claim 2, wherein the header including an OFDM mode bit, and the header further including a length field indicating the duration the second portion, in which the second portion comprising an OFDM synchronization pattern, an OFDM signal symbol, and an OFDM payload.

4. A dual packet configuration as claimed in claim 3, including the OFDM signal symbol including a data rate section and a data count section, and in which the first portion based on a first clock fundamental, and the second portion based on a second clock fundamental.

5. A dual packet configuration as claimed in claim 4, wherein the first clock fundamental is approximately 22 Megahertz (MHz) and the second clock fundamental is approximately 20 MHz.

6. A dual packet configuration as claimed in claim 4, wherein the first and second portions are based on a single clock fundamental, with the second portion including OFDM symbols, each OFDM symbol includes a guard interval with a standard number of samples for OFDM, or with an increased number of samples.

7. A dual packet configuration as claimed in claim 6, including the second portion including OFDM symbols wherein each OFDM symbol includes a reduced number of frequency subcarriers, and preferably each OFDM symbol includes 48 frequency subcarriers.

8. A dual packet configuration as claimed in claim 7, wherein each of the frequency subcarriers is a data subcarrier, the frequency subcarriers include at least one pilot tone, and in which a subset of the data subcarriers is discarded and replaced with a corresponding number of pilot tones for transmission, and wherein upon reception the discarded data subcarriers are recreated using received data.

9. A wireless communication device that is configured to communicate using a dual packet configuration, comprising a transmitter configured to transmit packets with a dual configuration, a receiver configured to receive packets with a dual configuration, and the dual

packet configuration including first and second portions, the first portion modulated according to a serial modulation method and the second portion modulated according to a parallel modulation method, and in which the serial modulation is direct sequence spread spectrum (DSSS) and the parallel modulation method is orthogonal frequency division multiplexing (OFDM).

10. A wireless communication device as claimed in claim 9, wherein the first portion including a header with an OFDM mode bit, the header including a length field indicating the duration of the second portion, and comprising a first clock source based on a first clock fundamental, the first portion based on the first clock fundamental, and a second clock source based on a second clock fundamental, the second portion based on the second clock fundamental.

11. A wireless communication device as claimed in claim 10, wherein the first clock fundamental is approximately 22 Megahertz (MHz) and the second clock fundamental is approximately 20 MHz, including a clock source based on a clock fundamental, the first and second portions based on the clock fundamental, the second portion includes OFDM symbols, each OFDM symbol including a guard interval with a standard number of samples for OFDM, or with an increased number of samples.

12. A wireless communication device as claimed in claim 11, wherein the second portion includes OFDM symbols, each OFDM symbol including a reduced number of frequency subcarriers, each of the frequency subcarriers is a data subcarrier, and the frequency subcarriers include at least one pilot tone.

13. A wireless communication device as claimed in claim 12, including the transmitter discarding at least one of the data subcarriers and replacing the discarded data subcarriers with a corresponding number of pilot tones, and the receiver regenerating the discarded data subcarriers based on received data subcarriers, the transmitter and receiver each capable of communicating in a super short mode in which only the second portion modulated according to the parallel modulation is utilized, or the transmitter and receiver each capable of communicating in a standard mode in which the second portion is modulated according to the serial modulation, and preferably the transmitter and receiver each configured to operate in the 2.4 gigahertz frequency band.

14. A method of wireless communication using a dual packet configuration, comprising modulating a first portion of each packet according to a serial modulation, and modulating a second portion of each packet according to a parallel modulation, the modulating a first portion of each packet comprising modulating according to direct sequence spread spectrum (DSSS),

and the modulating a second portion of each packet comprising modulating according to orthogonal frequency division multiplexing (OFDM).

15. A method as claimed in claim 14, characterized by including a header with an OFDM mode bit in the first portion, and including a length field in the header indicating a duration of the second portion, the modulating a first portion of each packet comprising modulating based on a first clock fundamental, and the modulating a second portion of each packet comprising modulating based on a second clock fundamental, in which the modulating first and second portions of each packet comprises modulating based on a single clock fundamental.

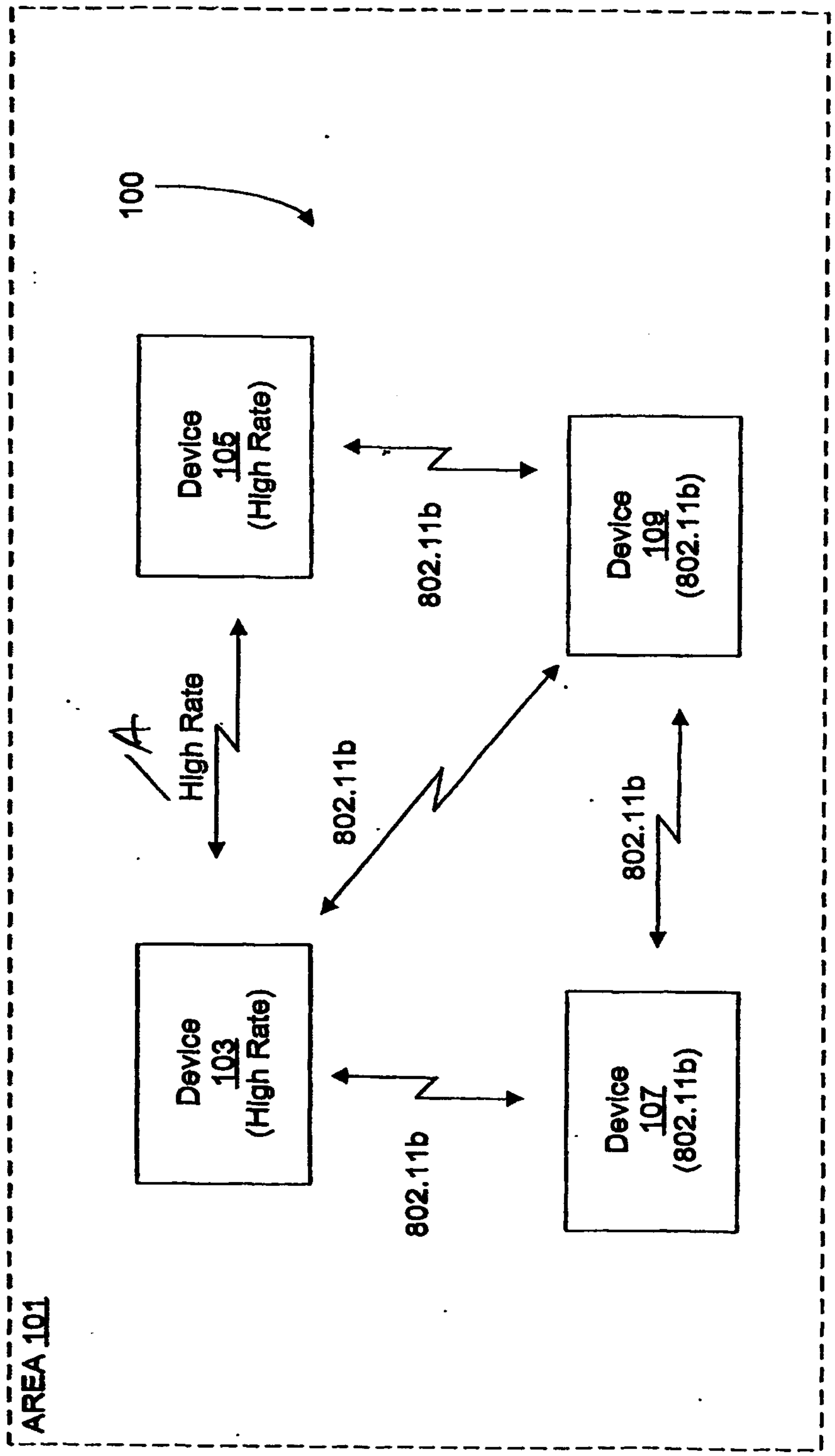

100
AREA 101
Device
105
(High Rate)
Device
103
(High Rate)
Device
109
(802.11b)
Device
107
(802.11b)
High Rate
802.11b
802.11b
802.11b
802.11b

FIG. 1

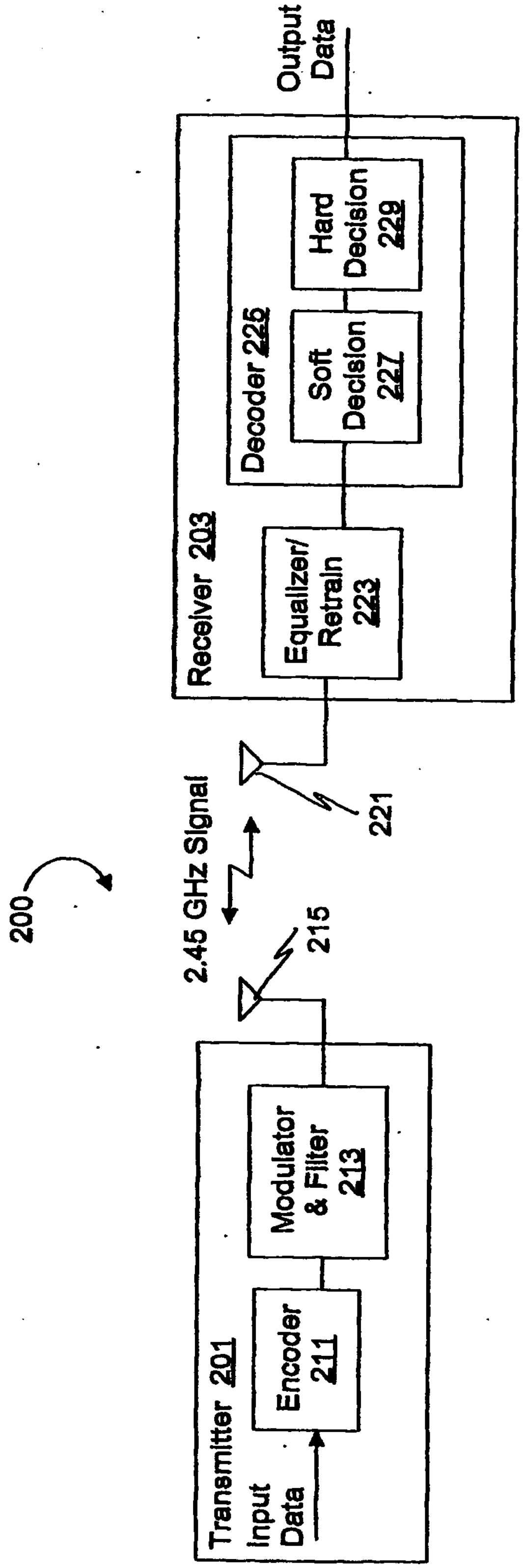

Output Data
Receiver 203
Decoder 225
Equalizer/ Retrain 223
Soft Decision 227
Hard Decision 229
221
2.45 GHz Signal
200
215
Transmitter 201
Input Data
Encoder 211
Modulator & Filter 213

FIG. 2

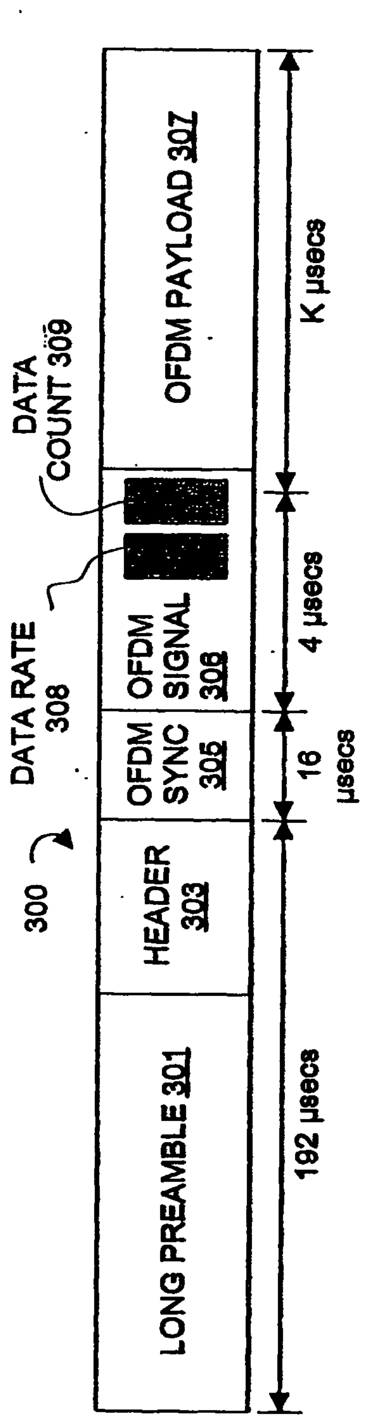

300
LONG PREAMBLE 301
HEADER 303
OFDM SYNC 305
OFDM SIGNAL 306
OFDM PAYLOAD 307
DATA RATE 308
DATA COUNT 309
192 µsecs
16 µsecs
4 µsecs
K µsecs

FIG. 3A

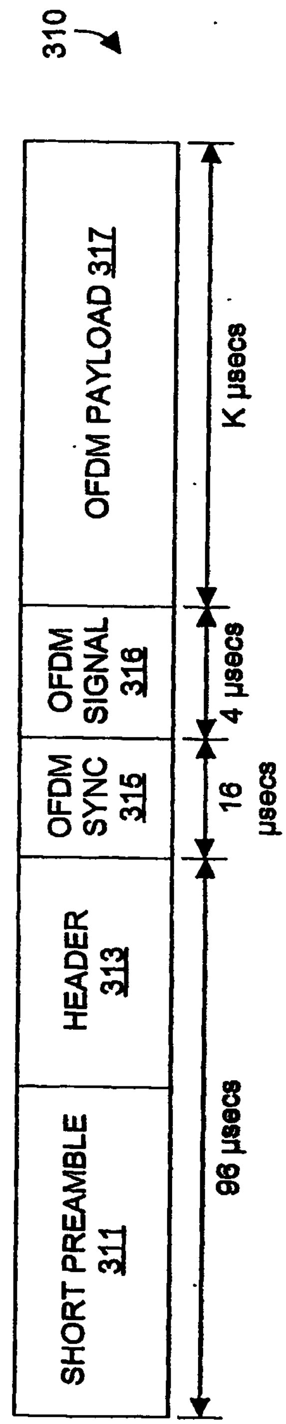

310
SHORT PREAMBLE 311
HEADER 313
OFDM SYNC 315
OFDM SIGNAL 316
OFDM PAYLOAD 317
96 µsecs
16 µsecs
4 µsecs
K µsecs

FIG. 3B

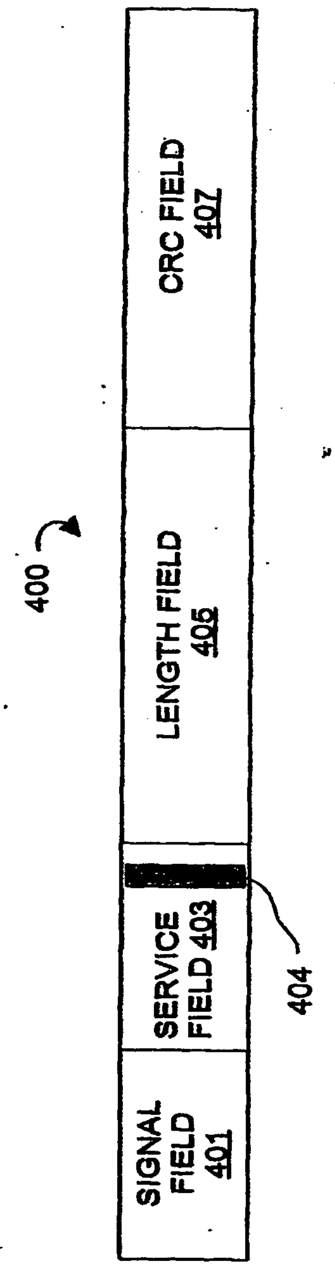

400
SIGNAL FIELD 401
SERVICE FIELD 403
404
LENGTH FIELD 405
CRC FIELD 407

FIG. 4

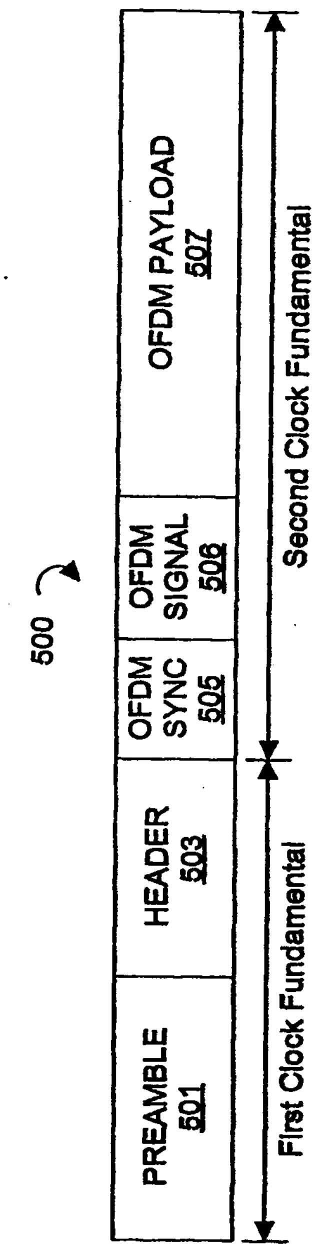

500
PREAMBLE 501
HEADER 503
OFDM SYNC 505
OFDM SIGNAL 506
OFDM PAYLOAD 507
First Clock Fundamental
Second Clock Fundamental

FIG. 5

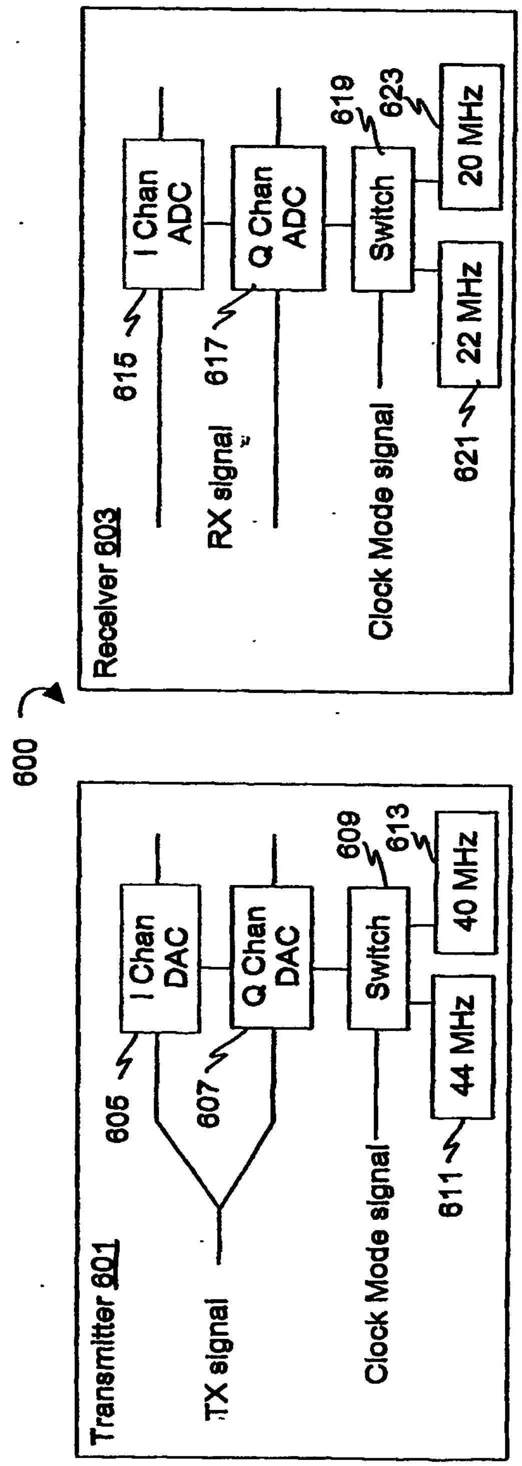

600
Transmitter 601
TX signal
Clock Mode signal
I Chan DAC
Q Chan DAC
Switch
44 MHz
40 MHz
605
607
609
611
613
Receiver 603
RX signal
Clock Mode signal
I Chan ADC
Q Chan ADC
Switch
22 MHz
20 MHz
615
617
619
621
623

FIG. 6A

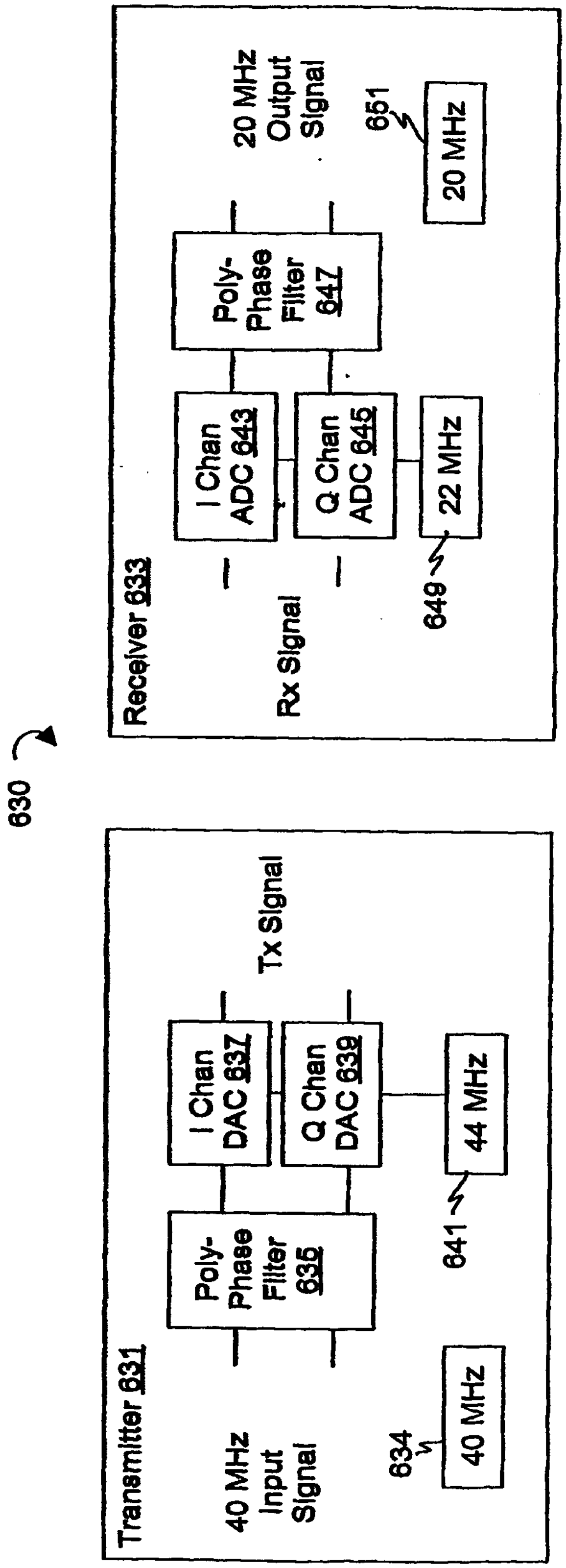

630
Transmitter 631
40 MHz Input Signal
Poly-Phase Filter 635
I Chan DAC 637
Q Chan DAC 639
Tx Signal
634
40 MHz
641
44 MHz
Receiver 633
Rx Signal
I Chan ADC 643
Q Chan ADC 645
Poly-Phase Filter 647
20 MHz Output Signal
649
22 MHz
651
20 MHz

FIG. 6B

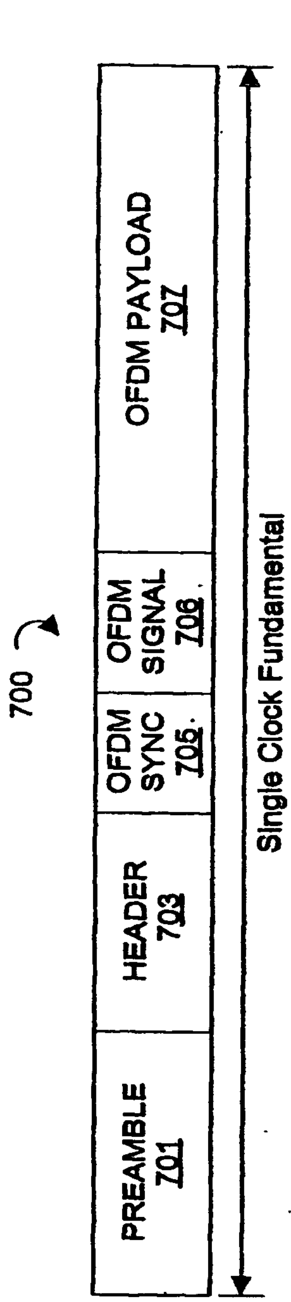


FIG. 7A

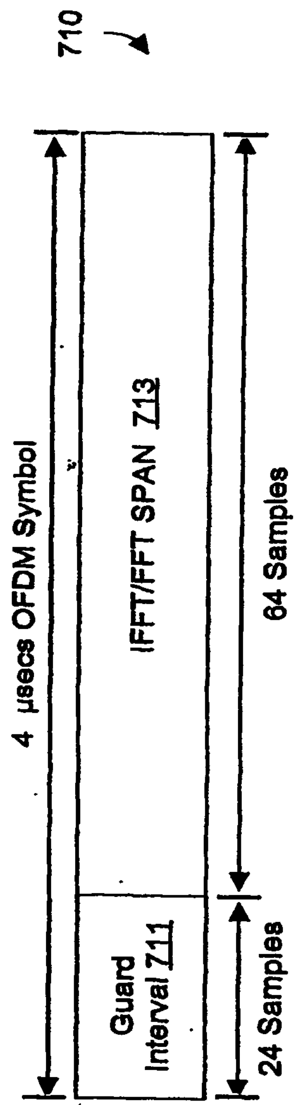


FIG. 7B

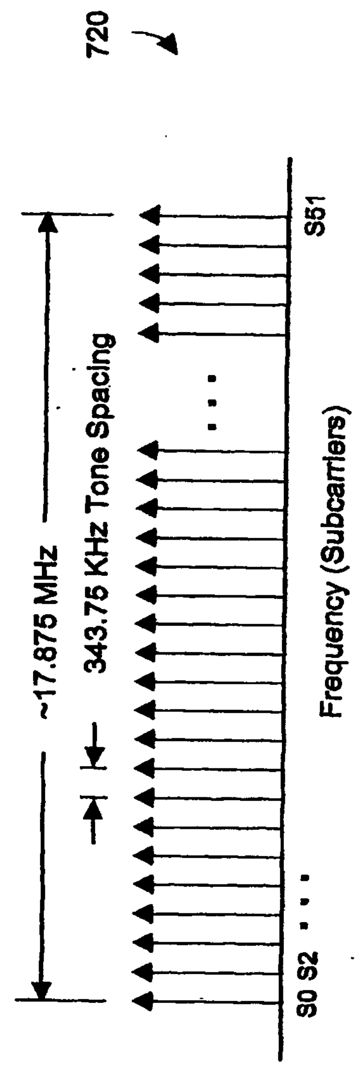


FIG. 7C

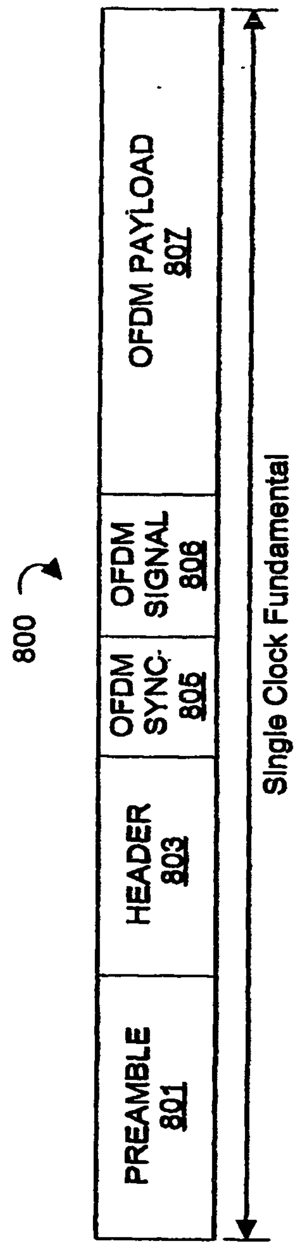


FIG. 8A

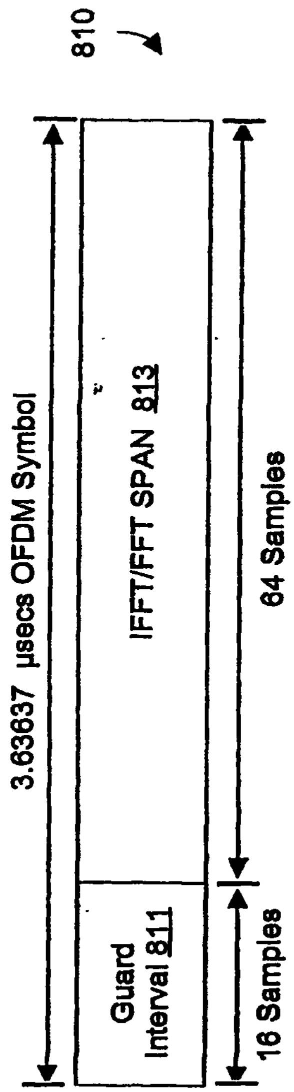


FIG. 8B

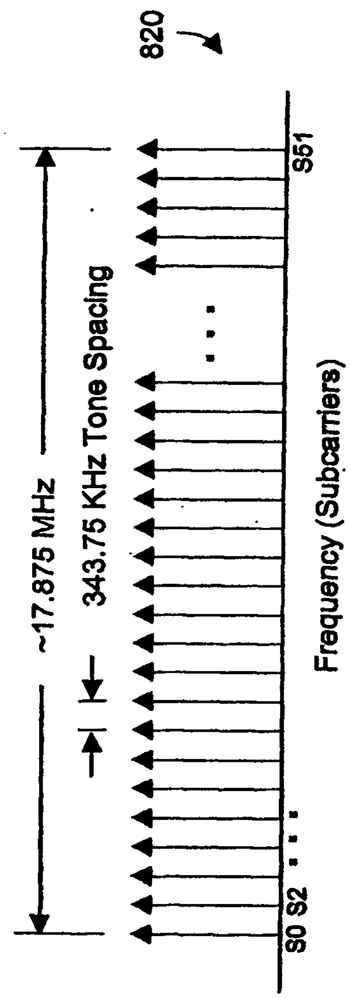


FIG. 8C

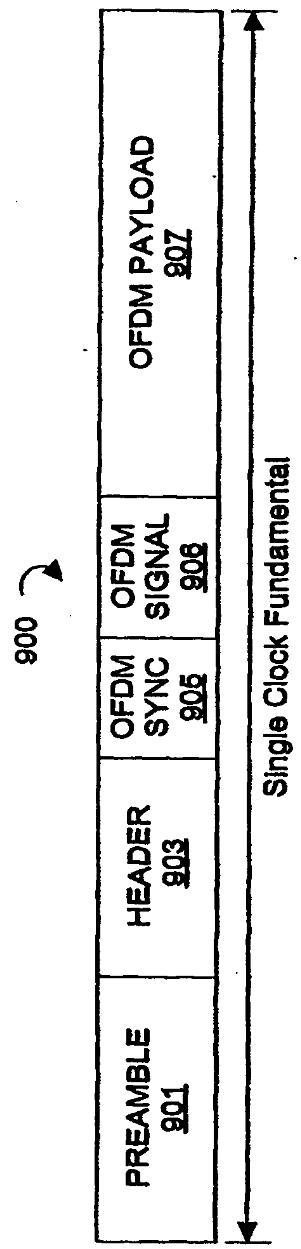


FIG. 9A

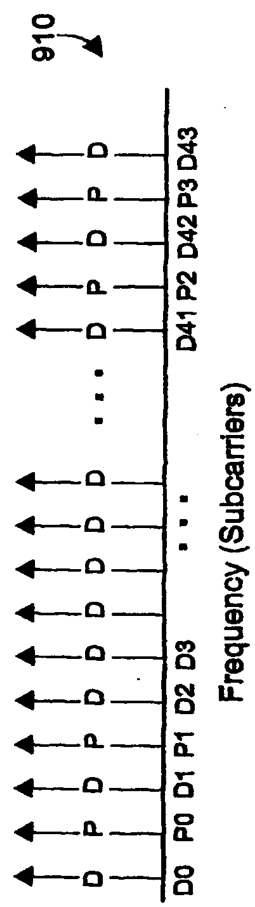


FIG.9B

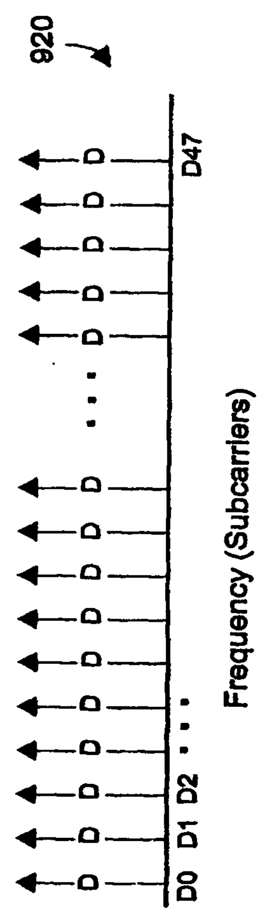


FIG. 9C

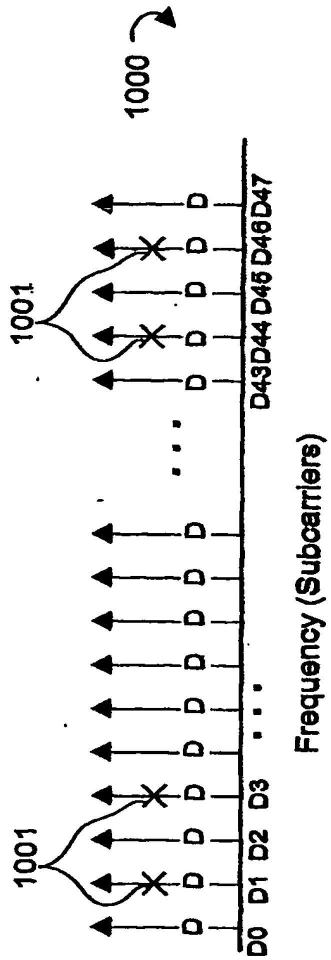


FIG. 10A

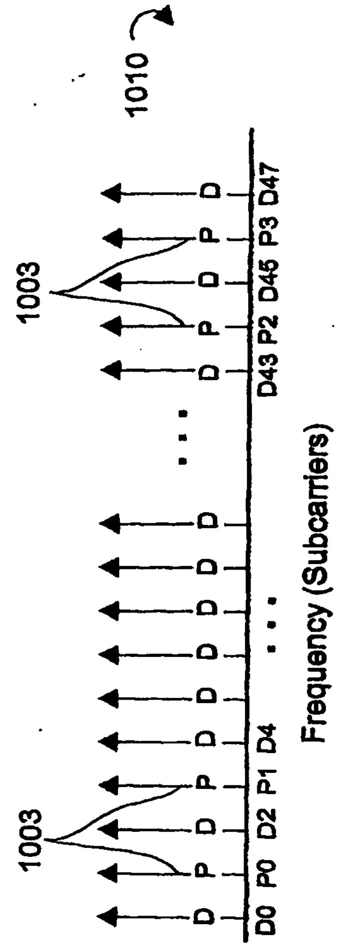


FIG. 10B

Comparson of Embodiments

Embod. #	Provided Data Rates (Mbps)	Clock Rate (MHz)	# of Sub-carriers	# of Pilot Tones	# Samples Cyclic Ext.	# Samples FFT	OFDM Symbol Duration (usecs)	Spectral Width (relative to 802.11a)	ThermalNoise Performance (Eb/No dB) (relative to 802.11a)	Delay Spread Performance (RMS DS) (relative to 802.11a)	Comments
1 (500)	6, 9, 12, 18, 24, 36, 48, 54	20	52	4	16	64	4	same	same	802.11a	Clock switch between 20 & 22 MHz
2 (700)	6, 9, 12, 18, 24, 36, 48, 54	22	52	4	24	64	4	10% wider	0.5 dB worse	50% better	Clock switch not required; Added samples to cyclic extension
3 (800)	6.6,9.9,13.2,19.8, 26.4, 39.6, 52.8,59.4	22	52	4	16	64	3.63637	10% wider	same	10% worse	802.11a run at 22 MHz; 10% increase in data rates
4 (900, 710, 910)	5.5, 8.25, 11, 16.5, 22, 33, 44, 49.5	22	48	4	24	64	4	0.83% wider	0.5 dB worse	50% better	44 data sub-carriers; Added samples to cyclic extension
5 (900, 710, 920)	6, 9, 12, 18, 24, 36, 48, 54	22	48	0	24	64	4	0.83% wider	0.5 dB worse	50% better	48 data sub-carriers; No pilots; Added samples to cyclic extension
6 (900, 710 1000,1010)	6, 9, 12, 18, 24, 36, 48, 54	22	48	4	24	64	4	0.83% wider	0.9 dB worse	50% better	Puncture 4 of the 48 data sub-carriers Replace with 4 pilots; Added samples to cyclic extension
7 (900, 810, 910)	6.05, 9.075, 12.1, 18.15, 24.2, 36.3, 48.4, 54.45	22	48	4	16	64	3.63637	0.83% wider	same	10% worse	44 data sub-carriers 4 pilots
8 (900, 810, 920)	6.6, 9.9, 13.2, 19.8, 26.4, 39.6, 52.8, 59.4	22	48	0	16	64	3.63637	0.83% wider	same	10% worse	48 data sub-carriers. No pilots.
9 (900, 810 1000,1010)	6.6, 9.9, 13.2, 19.8, 26.4, 39.6, 52.8, 59.4	22	48	4	16	64	3.63637	0.83% wider	0.4 dB worse	10% worse	Puncture 4 of the 48 data sub-carriers Replace with 4 pilots

FIG. 11

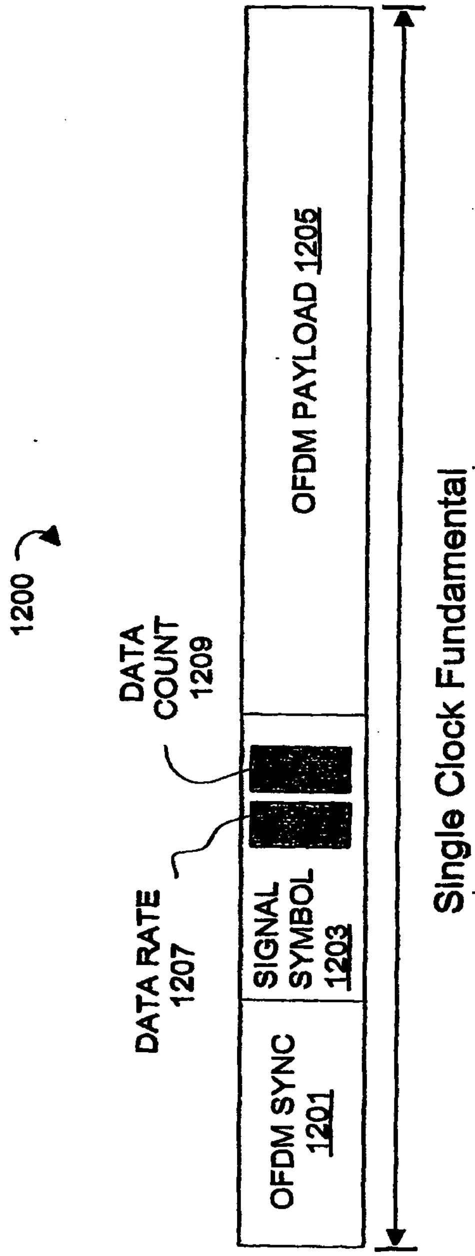

1200
DATA RATE
1207
DATA
COUNT
1209
OFDM SYNC
1201
SIGNAL
SYMBOL
1203
OFDM PAYLOAD 1205
Single Clock Fundamental

FIG. 12

Distributed contention-free traffic scheduling in IEEE 802.11 multimedia networks

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Abstract— **Wireless local area networks are a promising solution to support advanced data services in mobile environments. The IEEE 802.11 wireless LAN standard is emerging as a mature technology to support delay sensitive network services. In order to support these services the standard has proposed the use of a polling scheme; however, existing polling schemes require high communication overheads or suffer from unfairness. In this paper, we propose a distributed fair queueing algorithm, "distributed deficit round robin", which is compatible with the 802.11 medium access control rules. Software simulation of this scheme shows that it can manage a heterogeneous mix of delay sensitive traffic.**

Key Words— Round robin, Fair queueing, Medium access control, Polling, Scheduling, Wireless local area networks

I. INTRODUCTION

Packet networks with advanced data services such as video, audio, voice and images have become a standard method of communication and people will soon be demanding these services in mobile environments. This has stimulated research into developing wireless multimedia networks to support a wide range of services with an acceptable level of performance.

Currently Wireless Local Area Networks (WLAN) technology is supported by two main standards: the IEEE 802.11 standard [26] and the High Performance Radio LAN (HIPERLAN) standard [23], developed by the European Telecommunication Standards Institute (ETSI). This work focuses on 802.11.

The 802.11 medium access control (MAC) protocol specifies a polling mechanism for delay sensitive data. However, the standard does not define the order of polling. In order to support multimedia services with diverse, sometimes contradictory qualities of service (QoS) requirements [7][2], an efficient packet scheduler is required. In particular, since services have varying bandwidth requirements, it must ensure a fair distribution of bandwidth. On the downlink, standard fair queueing (FQ) algorithms can be used, such as the Deficit Round Robin (DRR) algorithm described in [22]. Fair allocation of bandwidth to uplink traffic is more difficult as the details of packets awaiting transmission are decentralized. Most of the proposed scheduling schemes for uplink traffic either suffer from unfairness or require a continuous exchange of information regarding the status of distributed queues. The 802.11 standard, however, does not support exchanging explicit information. In this paper, we examine a distributed FQ strategy, "Distributed Deficit Round Robin" (DDRR) [19][20], recently proposed by the authors.

We also present a complete scheduling scheme for 802.11 WLANs combining the DDRR and DRR strategies. The performance of this combined scheme and its interaction with asynchronous traffic are evaluated by software simulation. This algorithm can be used for both symmetric and asymmetric traffic and its efficiency can be improved by using the more data bit field of the MAC header for detecting empty queues.

This paper is organized as follows. The next section outlines the basics of 802.11 access control mechanisms and the important protocol features. Section III describes some existing schemes for polling list management, assessing their compatibility with the 802.11 MAC protocol. In Section IV we describes the Distributed Deficit Round Robin scheme. The combined scheduling scheme is detailed in Section V. Section VI presents the simulation model and the simulation results are presented in Section VII.

II. IEEE 802.11 ACCESS PROTOCOLS

This section briefly summarises some of the features of the 802.11 MAC sublayer.

A. Contention-based and Contention-free access

The IEEE 802.11 MAC layer supports two access modes, the distributed coordination function (DCF) and the point coordination function (PCF). These two modes provide contention-based and contention-free (CF) access to the physical medium. The physical transmission time is divided into cycles and each cycle is further divided into two time periods, a contention period (CP) and a contention-free period (CFP), which correspond to DCF and PCF respectively. This arrangement, shown in Figure 1, guarantees channel access to both asynchronous traffic and time-bounded traffic in each cycle.

B. *Distributed Coordination Function*

A station wishing to transmit a data packet under DCF must sense the medium before starting the transmission. If the medium is busy, the transmission is deferred: the station backs off for a random time interval uniformly distributed in a prespecified range. If the station senses an idle channel, it makes sure that the channel is idle for a minimum time period (DIFS) and then starts the transmission. This is shown in Figure 2, taken from [1].

C. *Point Coordination Function:*

PCF mode is controlled by a Point Coordinator (PC), which operates from a centralized "access point", analogous to the base station in a cellular network. The PC transmits a beacon frame (**B** in Figure 1) to announce the CFP to all stations. This puts the stations in a hold state in which they cannot transmit in DCF mode. The PC then polls the stations in the polling list according to a predetermined strategy. Once a station is polled, it has the right to transmit a single frame while all the other stations remain idle. Stations with no time-bounded packets waiting for transmission will respond with a CF-NULL frame. The CFP Repetition interval (Figure 1) describes the rate at which the CF cycle occurs. The length of the CF period is bounded above by `CFP_Max_Duration`.

D. *The Polling List*

Stations having delay sensitive data to transmit will compete for the channel together with asynchronous stations, in order to be admitted into the polling list. Once the PC receives an "association", it inserts the station into the polling list. PC polls the stations in polling list during the CF transmission period.

E. *The "More Data" bit*

The 802.11 MAC header contains a single bit "more data" field. In each poll response sent back to the PC, a station sets the "more data" bit if and only if it has packets waiting to be sent. This can be used to reduce the polling of empty queues.

F. *Transmission acknowledgements*

Each MAC protocol data unit (MPDU) transmitted under either access mode must be acknowledged by the recipient at the MAC layer. In order to save bandwidth, the standard allows this acknowledgement to be combined with one of the CF-Poll, Data or CF-End frames. Details of these two access mechanisms can be found in [1][8][25][26].

III. CONTENTION FREE ACCESS MANAGEMENT

As proposed in the 802.11 standard, the PCF access mode uses a polling scheme to distribute the bandwidth during the contention free (CF) period. This section discusses the need for a FQ strategy and reviews some of the existing centralized and distributed FQ schemes, identifying the problems for implementing them on 802.11.

A. *Traffic stream management in the downlink*

The scheduler running at the PC may use non-limited scheduling policies such as first-come first-serve (FCFS) or deadline-ordered scheduling disciplines [11] to handle the downlink traffic. As we consider networks carrying a heterogeneous mix of delay sensitive traffic, these disciplines may cause unfairness for some traffic flows. Therefore, service disciplines which can limit the amount of traffic transmitted by each flow are more attractive than non-limited service disciplines.

The primary goal of FQ [10][13][24][27] is to distribute the bandwidth equally among all competing sessions. In FQ, users with moderate bandwidth requirement are not penalized because of excessive demands of others. FQ has been enhanced to allow for weighted assignment of bandwidth [3][4]. The round robin service discipline gives equal bandwidth to all the queues if the average packet size over the duration of a flow is the same for all flows [18]. However, when the lengths of packets are not the same and/or the service shares assigned to the sessions are not equal, the definition of fair queueing and the right order of providing service to the sessions becomes a more subtle matter [13]. This is the case in multimedia networks since for example, video packets will typically be larger than voice packets.

A simple FQ algorithm called Deficit Round Robin (DRR) [22] was proposed by Shreedhar *et al.*. In DRR, each queue, *i*, waiting for service has a *deficit counter* (DC_i). At the start of each round, DC_i is incremented by a specific service share, or *quantum*, Q. If DC_i is less than the length of the next packet, then the scheduler moves to queue i+1 without servicing queue i. Otherwise, it sends the packet and reduces DC_i by the packet length. That means that queue i has to wait until enough credit is accumulated on DC_i before receiving the service. The DC_i is reset to 0 whenever the i^{th} queue becomes empty. Clearly, the DRR scheduler requires knowledge of the length of the next packet.

B. *Traffic stream management in uplink*

Unlike downlink flows, the uplink traffic flows in wireless networks are decentralized (localized to the stations) and the scheduler has limited information about these queues. Therefore, most FQ schemes cannot be directly used on the uplink.

The polling schemes investigated in [5][6][15] for multiplexing heterogeneous traffic in WLANs make no attempt to ensure fairness. Schemes based on peak rate reservation and fixed frame length, like R-Aloha [9] and PRMA [14], may result in under-utilization of network

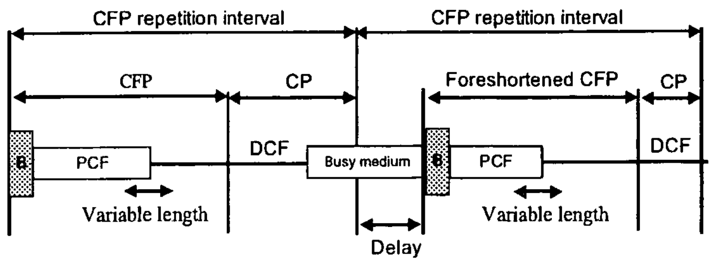

Figure 1. CFP/CP alternation within the contention-free repetition interval

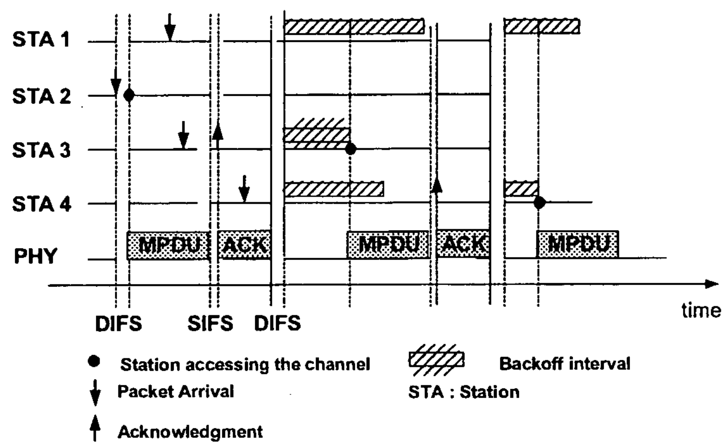

Figure 2. BASIC ACCESS MECHANISM OF 802.11

resources if the peak-to-average ratios are high. Distributed self-clock fair queueing [16], Fully Gated Limited (FGL) and non-uniform FGL polling schemes [17] are some of the fair queueing schemes proposed for managing distributed uplink traffic.

Implementation of these FQ schemes requires a continuous exchange of explicit information regarding the distributed queues. As the proposed 802.11 MAC protocol does not support exchanging additional packets either at the beginning of each CF period or during the CF period, the schemes described above cannot be used at the PC. One may think of using the standard round robin scheme which would work with the 802.11 MAC protocol for polling list management. However, round robin is unfair if traffic streams have different average packet lengths. This paper mainly focuses on a scheduler based on a distributed FQ scheme for uplink traffic in an 802.11 WLAN carrying a heterogeneous mix of delay sensitive traffic. The scheme is a distributed form of the DRR scheme and is described in the following section.

IV. DISTRIBUTED DEFICIT ROUND ROBIN

The Distributed Deficit Round Robin (DDRR) scheme [19][20] is based closely on DRR. Each admitted connection i is again assigned a Deficit Counter, DC_i', which is incremented by the quantum, Q, in a round robin fashion. However, as soon as DC_i' becomes positive, the scheduler allows the i^{th} queue to send one packet. After that, DC_i' is decremented by L_i, where L_i includes both the length of the transmitted packet and the polling and transmission overhead. This is repeated as long as DC_i' remains positive. If $DC_i' \le 0$, then the scheduler does not poll the i^{th} queue, instead moving to the next entry in the polling list. Therefore servicing the i^{th} queue is backlogged to the next cycle.

As in DRR, DC_i' is reset to 0 whenever the i^{th} queue becomes empty. DDRR can sense that a queue is empty when it receives an empty response to its poll. This unnecessary poll can be eliminated if we assume that the packet header has a single "more data" bit field, such as provided in 802.11.

Figure 3 illustrates the operation of the DDRR scheduler with four queues. The scheduler goes through the complete polling list in round robin fashion (1,2,3,4,1,2...) checking the deficit counters. The scheduler increments the value of the corresponding DC_i' by the quantum, Q, before it checks whether $DC_i' > 0$. The crosshatched areas bounded by the dark lines represent the current levels of DC_i' of each station, after incrementing by Q. After adding Q to DC_2', it is still negative. The scheduler

thus bypasses station 2 and moves to station 3. After adding Q to DC_3', $DC_3'>0$, and hence the scheduler polls station 3, allowing it to transmit the next packet of length X. Then DC_3' is decremented by X. After that, $DC_3'<0$, and the scheduler moves to station 4.

Note that in DDRR, a packet is transmitted first and then the consumed bandwidth is "paid off". In contrast, under DRR a station must save enough credit prior to the packet transmission. This trivial change allows the scheduling to be performed on the distributed queue. The pseudo-code for the DDRR algorithm is given in the Appendix.

Figure 4 illustrates how the transmission of packets in the i^{th} queue is scheduled by DDRR. The rectangles on the left represent the length of the packets waiting for service at the station and the rectangles on the right represent the corresponding deficit counter maintained by the PC. In the first round, the i^{th} queue transmits the first two frames in the queue. After that DC_i' goes negative and the i^{th} queue is not permitted to transmit during the second round. By the third round, the i^{th} queue has "paid off" the consumed bandwidth and is allowed to continue its transmission.

A. Analytical results

Fairness can be quantified by $FM(t_1,t_2)$", which measures the maximum difference between the normalized service received by two backlogged sessions over the interval (t_1,t_2) in which both sessions are continuously backlogged. The following theorem shows that the fairness bounds for DDRR are the same as those of DRR (i.e. Theorem 3 [22]). In order to prove this result we make use of the following analogous of Lemmas 1 and 2 of [22].

Lemma 1: Each time the DDRR scheduler finishes processing one station, $-L_{max} < DC_i' \le 0$, for each i, where $-L_{max}$ is the maximum packet size.

Proof: As DC_i' is unaffected by the processing of stations other than station i, we need only consider the case of the scheduler finishing processing station i.

To see that $DC_i' > -L_{max}$, we argue as follows. Let X be the last packet transmitted by the i^{th} flow before finishing processing station i, and let $L(X)$ denotes the length of the packet X. Note that $L(X) \le L_{max}$. If no packet has ever been transmitted, $DC_i' \ge 0 > -L_{max}$, since DC_i' is initialised to 0. In order to allow the i^{th} queue to transmit packet X, DC_i' must have been positive after transmitting all the packets before packet X. That is,

$$DC_i' = \varepsilon$$

for some $\varepsilon > 0$. The value of DC_i' before the scheduler moves to the $(i+1)^{st}$ entry thus satisfies

$$DC_i' = \varepsilon - L(X) > -L_{max}.$$

It remains to show that $DC_i' \le L_{max}$. The DDRR scheduler only leaves queue i when either (a) queue i has exhausted its quota, indicated by $DC_i' \le 0$ or (b) the remote queue is empty, indicated by an empty packet or by a more data bit being reset. In the latter case, DC_i' is set to 0. Thus in either case $DC_i' \le 0$. Therefore $-L_{max} < DC_i' \le 0$ for each i when the DDRR scheduler finishes processing any station, as required.□

Lemma 2: Let queue i be backlogged during the time interval (t_1,t_2) of any execution. Let m be the number of round robin service opportunities received by the queue i during the interval (t_1,t_2). Then

$$m.Q_i - L_{max} \le \text{sent}_i(t_1,t_2) \le m.Q_i + L_{max} \quad ,$$

where $\text{sent}_i(t_1,t_2)$ is the number of bytes transmitted by the i^{th} backlogged session during the interval (t_1,t_2) and Q_i is the quantum assigned on i^{th} flow.

The proof of this lemma is analogous to the proof of Lemma 2 in [22].

Theorem 3: For interval (t_1,t_2) in any execution of the DDRR algorithm

$$FM(t_1,t_2) \le 2L_{max} + Q$$

where $Q = \min_i(Q)$ and

$$FM(t_1,t_2) = \max_{i,j\in B}\left(\frac{\text{sent}_i(t_1,t_2)}{f_i} - \frac{\text{sent}_j(t_1,t_2)}{f_j}\right)$$

where B is the set of backlogged sessions in the interval (t_1,t_2) and the quantity f_i expresses the ideal share to be used by flow I

Once again, the proof is analogous to Theorem 3 in [22].

V. COMBINED UPLINK AND DOWNLINK SCHEDULING

The scheduler must distribute the bandwidth fairly on both the uplink and the downlink. For each two-way session, the scheduler combining the DDRR and the DRR disciplines maintains two independent counters: one to control the uplink and one for the downlink. These counters are active only when the corresponding flow has joined the polling list. That means that it is possible for the downlink to be active while the corresponding uplink flow is inactive or vice versa.

If the scheduler can send poll requests to the stations combined with downlink data packets, it is possible to reduce the transmission overhead and hence to increase the overall transmission efficiency. The 802.11 standard supports this form of piggybacking.

This combined strategy is as follows. The i^{th} flow uses two deficit counters, DC_i' for the uplink and DC_i for the downlink, with the same quantum Q_i. Let L_i denote the length of the packet at the head of the i^{th} downlink queue including the transmission overhead. When the scheduler starts processing the i^{th} queue, after incrementing DC_i' and DC_i, there are four possibilities:

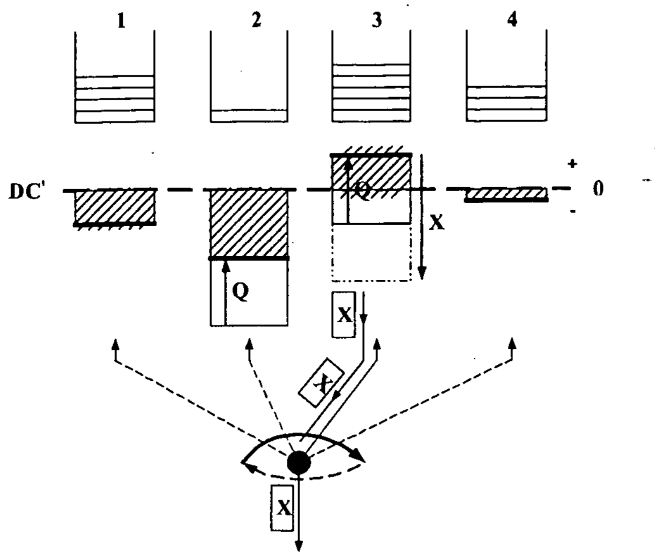

Fig. 3. DDRR servicing policy

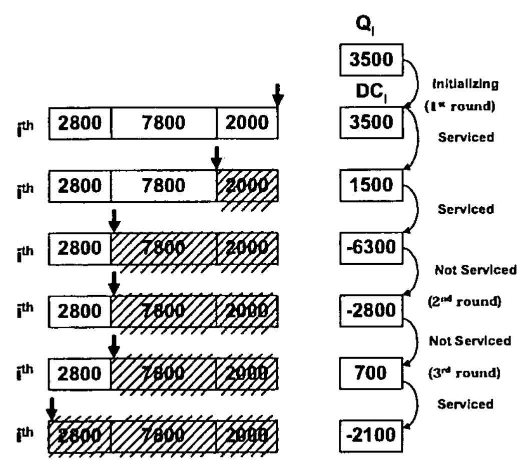

Fig. 4. Distributed Deficit Round-Robin scheme

1. $DC_i' > 0$, $DC_i \leq L_i$: A poll request is sent
2. $DC_i' \leq 0$, $DC_i > L_i$: The downlink packet is sent.
3. $DC_i' > 0$, $DC_i > L_i$: The packet is sent with a piggybacked poll request.
4. $DC_i' \leq 0$, $DC_i \leq L_i$: The scheduler moves to the next station in round robin order.

The deficit counters are then updated according to the DRR and DDRR rules. The DDRR scheduler uses the "more data" feedback bit as described in Section IV to reduce null frame transmissions. Moreover, the proposed scheduler deactivates these empty queues for the rest of the CFP. The scheduler continues to send polls to the stations until the expiration of `CFP_Max_Duration` or all the entries in the polling list become inactive, whichever occurs first. Thus the advantages of using "more data" bit is two fold: it can effectively use to reduce the chances of sending poll requests to empty uplink streams and it can also be used to detect the level of delay sensitive traffic. The scheduler is thus adaptive to delay sensitive traffic load.

Since there is no extra bandwidth required for a piggybacked poll request as suggested in the standard, the efficiency of the combined strategy can be further improved by sending a piggybacked poll request even when $DC_i' = 0$. This aspect has not been investigated in this work.

VI. SIMULATION DESCRIPTION

A WLAN carrying a mixture of real-time traffic and non-real-time asynchronous traffic was simulated with DDRR. This will be compared with the standard round robin (RR). When using RR, the more data bit was used in the same way as it was with DDRR.

A. Network system architecture

A single cell infrastructure WLAN was simulated with voice and video terminals communicating with a backbone network. There were also 10 asynchronous data terminals transmitting data packets among themselves, but not to or from the backbone network. This is illustrated in Figure 5.

B. Traffic models

The services in this experiment represent two classes of real-time traffic: an interactive low bandwidth class and a non-interactive high bandwidth class. Voice traffic was used to represent the interactive low bandwidth class and MPEG video traffic to represent non-interactive high bandwidth class. Note that the delay requirement of interactive traffic is more stringent than the delay requirement of non-interactive traffic. Even though we use a single traffic stream to represent each class, the assumption is that multiple streams would have comparable delay requirements had a source with multiple streams been used. If this is not the case, the node may use a method such as class base queueing (CBQ) [12] to distribute bandwidth among the competing streams.

Voice traffic: The voice source is modeled as Markov ON/OFF process with a talking state or a silent state. When the source is in the talking state it periodically generates fixed size voice packets. The CF repetition period was set to the inter-arrival time of these voice packets. Voice connections are full-duplex transmitting data in both the uplink and the downlink directions.

Video traffic: The video traffic sources generate frames at a constant rate. The lengths of the video frames were taken from the real traffic traces used in [21]. The video frames can be larger than the maximum MPDU length. These packets are segmented and sent to the MAC layer as a packet burst. Video connections are also full-duplex. When a video connection is set up, two randomly selected MPEG traces are attached to the uplink and downlink.

Data traffic: Asynchronous traffic transmitted during the contention period may delay the start time of CF cycles, and was included in our model. The data traffic was generated by 10 stations and had a Poisson arrival process and negative exponential packet lengths.

C. System parameters

We used the default values given in [26] for all the DCF and PCF related attributes. Tables I and II show important parameters of the simulation set up. The contention free repetition interval (20 ms) is partitioned into a contention-free period and a contention-based period. The boundary was variable but the contention-based period was at least 5 ms in each cycle to allow a maximum size MPDU to be transmitted.

VII. SIMULATION RESULTS

The network was subjected to three different types of traffic generated by data, voice and video terminals. Each simulation run consists of 175,000 CF cycles after a warm-up period of 5,000 cycles. Several tests were performed by varying both the contention free and the contention-based traffic loads to examine their interaction. We also found the number of full duplex voice and video connections that can be supported by a 10 Mbps 802.11 WLAN satisfying the following QoS requirements: This paper looks at the problem of maximising the number of connections while satisfying individual QoS requirements.

- 99% of the interactive (voice) MPDUs must be transmitted with MPDU delay less than 32 ms
- 99% of the non-interactive (video) MPDUs must be transmitted with MPDU delay less than 100 ms.

The "delay" refers to the access delay, which is the sum the MAC delay and the queueing delay. Note that the expired packets of all real-time sessions are discarded. Then contention-based traffic was varied after fixing the CF traffic for those identified values to maximise the overall network throughput.

A. Effect of "more data" bit on CF cycle length

Figures 6-8 show the contention free cycle length for three values of delay sensitive load (G_{CFP}) shown in Table III. The DDRR scheduler clearly detects the level of the contention free traffic and terminates the CF cycle as early as possible freeing the bandwidth for contention traffic.

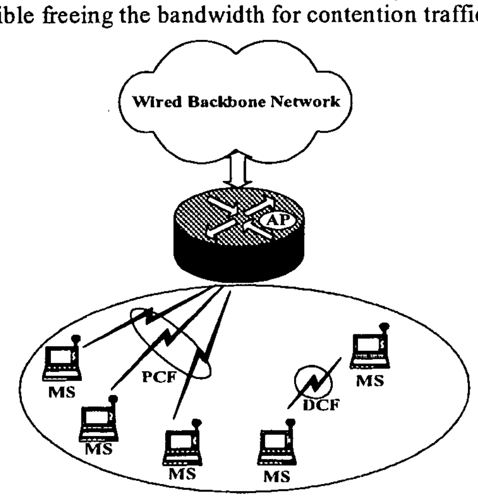

Fig. 5. Network architecture of interest

B. *Effect of real time traffic on asynchronous traffic delay*

The time bounded traffic load offered to the network affects the asynchronous traffic transmission as shown in Figure 9. With increasing CF load, the length of the contention-free transmission period increased, reducing the time available for contention-based transmission. Therefore packet latency increases for a given level of asynchronous traffic. As would be expected, the latency also increases for increasing contention-based load. Note that for a given total traffic, the contention-based delay increases as the proportion of CF traffic decreases, showing that PCF is more efficient than PCF.

C. *CF cycle length, data traffic and voice MPDU loss*

As mentioned earlier, voice packets are discarded if their waiting time exceeds 32 ms. The percentage voice MPDU loss will increase as the contention free load increases due to increasing queue delay, as shown in Figure 10. It also increases with increasing asynchronous load. This is because voice stations connect to the PC for each talk burst and there is higher probability that the association frames experience collisions.

Figure 11 shows the intensity of the voice MPDU loss for different combinations of contention-based and contention free loads. In this diagram, darker squares correspond to lower voice MPDU loss.

D. *IEEE 802.11 Network capacity under DDRR and RR*

Figure 12 shows the number of voice and video sessions that can be supported by the network satisfying the specified QoS measures under DDRR and RR. The term "session" refers to a full duplex connection in this context. When the offered network traffic is homogenous (points A and B in Figure 12), DDRR and RR perform similarly. However, for heterogeneous traffic, the average packet length varies between flows and RR becomes unfair. DDRR gives higher priority to the smaller but more frequent voice packets and thus increases the capacity. This confirms that DDRR scheduling outperforms RR for IEEE 802.11 wireless networks with a heterogeneous packet mix.

E. *CF traffic throughput*

Figure 13 shows how overall delay sensitive throughput varies with an increasing number of non-interactive (video) sessions when the network is presented with a mixture of interactive (voice) and video traffic subjected to the specified QoS constraints. This graph shows that throughput increases with increasing video traffic. This is because the delay requirement of the video (non-interactive) traffic is laxer than that of voice (interactive) traffic. Note that the throughput is calculated as a fraction of total channel capacity. Therefore cannot approach 100% because of the intrinsic polling and transmission overheads.

TABLE I. MAC AND PHY CHANNEL CONFIGURING ATTRIBUTES

Attributes	Value
PHY medium capacity	10 Mbps
Number of Data stations	10
CFP repetition interval	20 ms
CFP_Max_Duration	15 ms

TABLE. II. ATTRIBUTES OF VOICE AND VIDEO SOURCES

Attributes	Voice	Video
Average Source Rate (when active)	64 Kbps	0.4 Mbps
Frame Duration	20 ms	40 ms
Maximum Delay	32 ms	100 ms
Mean ON Duration	1.0 sec	N/A
Mean OFF Duration	1.35 sec	N/A
Quantum size	2208 bits	16524 bits

F. *Total throughput*

Figure 14 shows the total channel utilization by both CF traffic and contention-based traffic. The total channel utilization is obtained by optimizing the contention-based traffic for each combination of contention free traffic satisfying the QoS requirements of both voice and video, and then normalizing the sum of the throughputs of both contention-based and contention free traffic with respect to the total channel capacity. This shows that the PCF-DCF access mechanism proposed in the IEEE 802.11 standard achieves maximum of 69% channel utilization if DDRR/DRR scheme is employed to control the polling list management.

VIII. CONCLUSIONS

This paper has presented a fair queueing scheduler to control both uplink and downlink traffic in wireless LANs. The proposed scheme was evaluated by the software simulation of an IEEE 802.11 network. We examined the impact of the scheme on network capacity and how the scheme interacts with contention-based traffic.

It was shown that terminating the CF cycle when no stations have further data to transmit can increase the amount of bandwidth available for contention-based traffic and increase the overall network utilization.

It was also shown that asynchronous traffic can increase the delay of delay sensitive traffic, by colliding with the "control frames" used for establishing connections. This could be avoided by using alternative mechanisms to handle these control frames. Under the conditions studied, the 802.11 wireless LAN achieved between 50% and 69% utilization.

This demonstrates that the IEEE 802.11 MAC protocol point coordination function (PCF) can carry heterogeneous delay sensitive traffic and can coexist with the contention based distributed coordination function.

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TABLE. III. LOW, MEDIUM AND HIGH LEVELS OF CONTENTION FREE LOAD

	Figure 6	**Figure 7**	**Figure 8**
Number of voice sources	10	10	10
Number of video sources	0	3	6
Total normalized delay sensitive traffic load, (G_{CFP})	0.0524	0.2829	0.5295

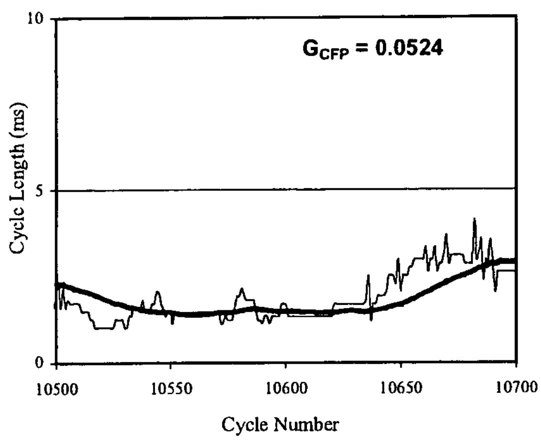

Fig. 6. Low level of delay sensitive load

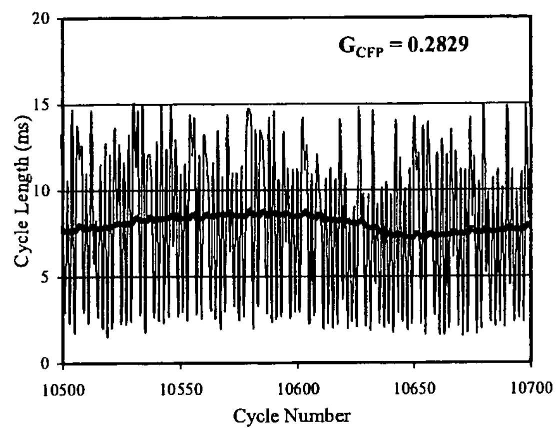

Fig. 7. Medium level of delay sensitive load

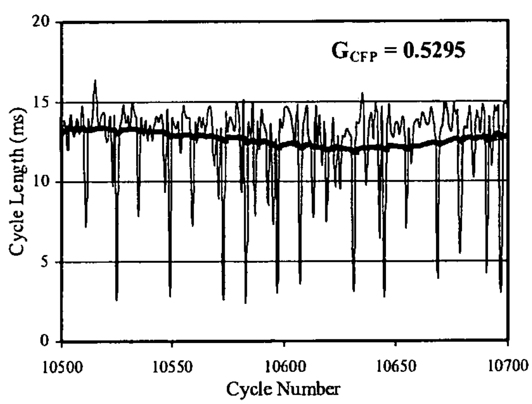

Fig. 8. High level of delay sensitive load

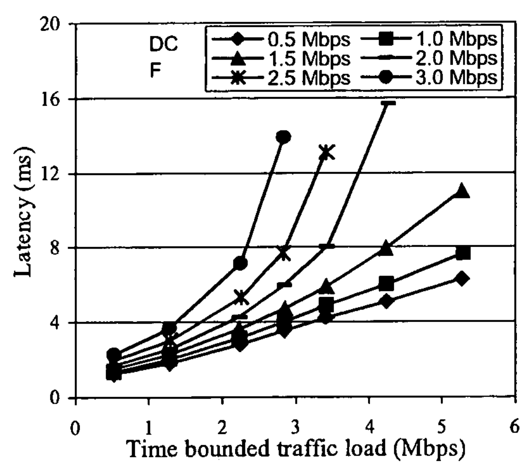

Fig. 9. Latency behaviour of the DCF

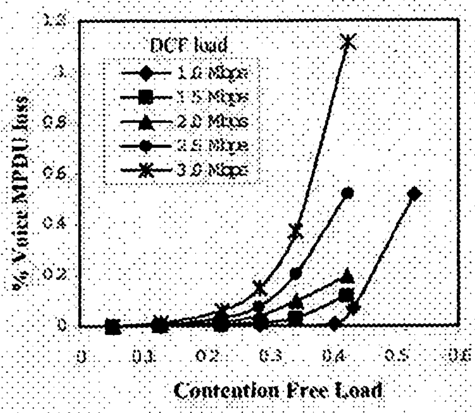

Fig. 10. Behaviour of voice MPDU loss

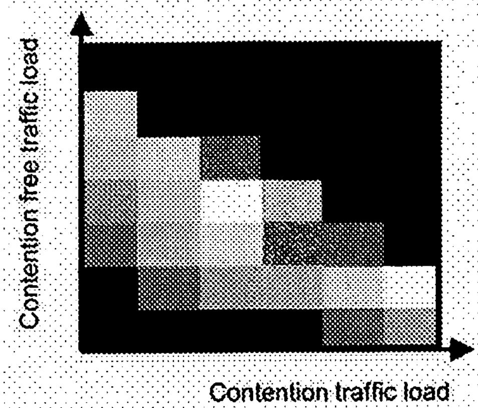

Fig. 11. Voice MPDU loss intensity

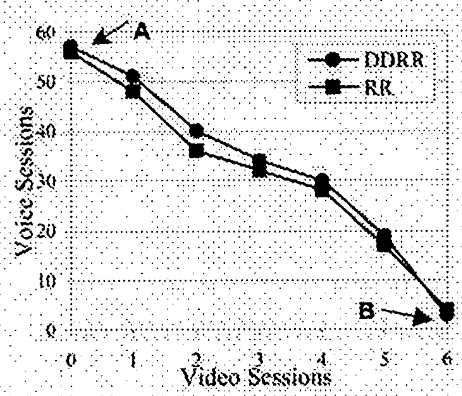

Fig. 12. Number of simultaneous voice and video

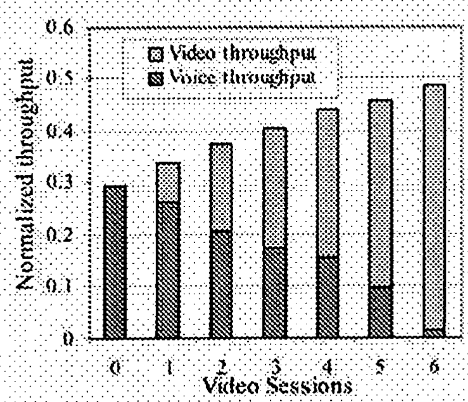

Fig. 13. Normalized CF throughput

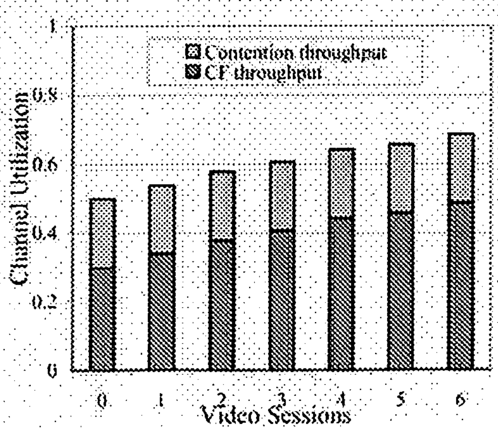

Fig. 14. Overall channel throughput

Appendix: DDRR Algorithm

```
At the start of each CF cycle:
  Mark all stations active
  WHILE ((SchedulingList not empty) AND
                (CF remaining time < CF MAX Duration) AND
                (NOT all stations inactive))
    DC_i' = DC_i' + Q_i;
    Set MoreData;
    WHILE ((DC_i > 0) AND (MoreData))
      Poll terminal i;
      Receive packet p;
      DC_i' = DC_i' − length of packet p;
      Read MoreData from p;
    END-WHILE
    IF (NOT MoreData)
      DC_i = 0;
      Make the i^th station inactive;
    END-IF
    i = i + 1;
  END-WHILE
```

TC2800 Jeff

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